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NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 77

Human Factors in the 21st Century

(Les facteurs humains au 21e siècle)

Papers presented at the RTO Human Factors and Medicine Panel (HFM) Specialists' Meeting held in Paris, France, 11-13 June 2001.

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

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- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS Studies, Analysis and Simulation Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

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Human Factors in the 21st Century

(RTO MP-077 / HFM-062)

Executive Summary

On 11th-13th June 2001, NATO members, representatives from Partnership for Peace nations, and Non-NATO nationals met in Paris to discuss the subject of Human Factors linked to developments in military affairs in the increasingly technological context of the 21st century. This meeting was part of the activities of the Human Factors and Medicine Panel of the North Atlantic Treaty Organisation's Research and Technology Organisation (RTO/HFM).

The revolution in military affairs, dating from the end of the Cold war, and the technology breakthroughs achieved in a number of different fields, lead us to look again in different ways at the place of the human operative in military activities and in particular at the place which should be allotted to him in complex socio-technical systems, with their difficult multilanguage, multisystem and multicultural contexts, in uncertain and ambiguous environmental and conflictual situations and from an increasingly broader and more integrated technological point of view.

The different groups worked on manpower, communications and management organisation in new, complex socio-technical systems, on technology and man-machine interface (MMI) related aspects and on medical implications.

A summary of the work undertaken during the specialists meeting was focussed down to a list of priorities selected from a number of fairly broad disciplinary fields identified as requiring a considerable amount of work in the HFM field.

It was considered that three approaches were particularly interesting, given their integrated response to the aims and priorities in question i.e.: first, a global interdisciplinary approach, enabling true systems engineering and human factors engineering integration, second, complex thinking as a way of responding to the need to stop dealing with problems one by one, in a static way, and third, the need to adopt an epistemological approach in the future in order to ensure the satisfactory overall positioning of the human being with respect to available techniques. Finally, multinational operations and in particular, operations other than war (OOTW) were considered as the military situation the most likely to benefit from the results achieved by these new approaches.

Les facteurs humains au 21e siècle

(RTO MP-077 / HFM-062)

Synthèse

Des membres de l'OTAN, des représentants des pays du Partenariat pour la Paix et des représentants de pays non membres de l'OTAN se sont réunis à Paris du 11 au 13 Juin 2001 pour discuter des Facteurs Humains liés aux évolutions des affaires militaires et dans un contexte technologique de plus en plus fort, à l'aube du 21ième siècle. Cette réunion de spécialistes faisait partie des activités de la Commission sur les facteurs humains et la médecine de l'Organisation pour la recherche et la technologie de l'OTAN (RTO/HFM).

La révolution dans les affaires militaires née de la fin de la guerre froide, et l'évolution technologique dans de nombreux domaines amènent à réfléchir à de nouveaux aspects de la place de l'humain dans l'activité militaire. En particulier, il faut s'intéresser à la place qui lui doit être spécifée dans les systèmes socio-techniques complexes, avec leur difficile contexte de multi-langues, de multi-systèmes et de multi-cultures, dans des situations de conflits et d'environnement ambigus et incertains, et dans une approche technique globale de plus en plus large et intégrée.

Les travaux des différents groupes ont porté sur les concepts des ressources humaines, d'organisation de management et de communication au sein des nouveaux systèmes socio-techniques complexes, sur les aspects liés à la technologie, les interfaces homme-machine (MMI), et les implications en matière de médecine.

Une synthèse des travaux de la réunion de spécialistes a permis de converger vers une liste de priorités, composée de différents domaines disciplinaires plus ou moins larges, dans lesquels un important travail dans le domaine HFM est à réaliser.

Il a été considéré que trois approches devaient plus particulièrement être abordées pour leurs capacités à répondre de manière intégrée aux objectifs et aux priorités : l'interdisciplinarité au niveau de l'approche globale pour permettre une véritable intégration de l'ingénierie système et de l'ingénierie facteurs humains, la pensée complexe comme moyen de répondre au besoin qui existe de ne plus traiter les problèmes de façon granulaire et en situation statique et le besoin de conduire une approche épistémologique pour assurer dans le futur un positionnement satisfaisant et global de l'homme et de la technique. Enfin, les opérations multinationales et en particulier les opérations autres que la guerre (OOTW), devaient être considérées comme les plus aptes à bénéficier des résultats de ces nouvelles approches.

Click inside the blue boxes or on the titles to view the corresponding section

(except for items marked in red, which were not available at the time of production)

Contents

* Due to the three (3) Keynote Addresses, the first paper presented has been numbered as Paper 4 (hence no Paper 1, 2 or 3).

† Paper not available at time of production.

Human Factors and Medicine Panel

Chairman:

Col. W.C.M. TIELEMANS, MD
RNLAF/SGO
P.O. Box 20703
Binckhorstlaan, 135
2500 ES The Hague
THE NETHERLANDS

Vice-Chairman:

Dr Robert ANGUS
Director General
Defence Research Establishment Suffield
Box 4000 - Station Main
Medicine Hat, Alberta T1A 8K6
CANADA

PROGRAMME COMMITTEE

Chairmen

Dr Didier BAZALGETTE
Responsable Facteurs Humains
DGA/DSP/STTC/DT/SH
Ministère de la Défense
26, Boulevard Victor
00457 ARMEES
FRANCE

Miss Joanne MARSDEN
Room 502, Metropole Building
Northumberland Avenue
London WC2N 5BP
UNITED KINGDOM

Members

Prof. Dr Bernhard DOERING
Forschungsgesellschaft für Angewandte
Naturwissenschaften (FGAN-FKIE)
Neuenahrerstr. 20
D-53343 Wachtberg-Werthhoven
GERMANY

Dr Ken BOFF
Human Effectiveness Directorate
Air Force Research Laboratory (AFRL/HE)
2610 Seventh Street
Wright-Patterson AFB,
OH 45433-7901
UNITED STATES

PANEL EXECUTIVE

Dr C. WIENTJES
BP 25
F-92201 Neuilly-sur-Seine Cedex, FRANCE
Tel: +33 1 55 61 22 60/62
Fax: +33 1 55 61 22 98
E-mail: wientjesc@rta.nato.int or pelatd@rta.nato.int

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Rapport d'évaluation technique

Dr. Didier Bazalgette
DGA/DSP/STTC/DT/SH
Ministère de la Défense
26, Boulevard Victor
00457 ARMEES – FRANCE

Introduction

Du 11 au 13 juin 2001, des représentants de pays de l'OTAN, du Partenariat pour la Paix et de pays n'appartenant pas à l'OTAN se sont rencontrés à Paris (Hôpital du Val de Grâce) pour une réunion de spécialistes dont le thème était : les problèmes liés aux facteurs humains au 21ème siècle. Cette réunion s'est attachée plus particulièrement aux problèmes liés aux facteurs humains apparus depuis ce qu'il est convenu d'appeler la révolution dans les affaires militaires et qui a commencé avec la fin de la guerre froide.

Cette réunion a eu lieu en parallèle avec un atelier organisé conjointement du 13 au 15 juin 2001 par la DGA (Délégation Générale pour l'armement du ministère de la défense français), l'ONRIFO (Office of Naval Research Field Office) et la société THALES sur le thème de la prise de décision au 21ème siècle.

Thème et présentation d'ensemble.

La révolution dans les affaires militaires a déjà eu un profond impact sur les concepts des opérations militaires. La notion de confrontations massives entre adversaires disposant de technologies de pointe a été largement remplacée par la croyance en des conflits futurs délocalisés et associés à des mesures d'imposition ou de maintien de la paix.

De plus, en raison des avancées technologiques dans le domaine des senseurs et des systèmes d'information et de communication mais aussi dans la nanotechnologie et la biotechnologie, les systèmes d'armes deviendront de plus en plus intelligents. Ceci ouvre des perspectives sur des opérations militaires pratiquement autonomes, avec des combattants éloignés de la zone de conflits et sur une tendance à se diriger vers le champ de bataille virtuel. A l'autre extrémité du spectre se trouve la perspective d'une coalition de pays d'origines différentes, OTAN, PpP et non-membres de l'Alliance qui pourront déployer des forces dans les zones des conflits. Dans ce type d'opérations, les difficultés sont dues aux environnements multilingues et multi culturels dans lesquels les forces seront amenées à évoluer (et ceci s'applique aussi bien aux membres de la coalition qu'aux acteurs de la crise).

En d'autres termes, la révolution dans les affaires militaire ne va pas seulement se poursuivre, elle va s'accélérer et ceci aura inévitablement des implications pour les autorités militaires comme pour les combattants individuels, mais aussi pour ceux chargés du contrôle des armes et des plates-formes.

Lorsqu'on s'intéresse aux facteurs humains découlant de cette révolution dans les affaires militaires, il faut se concentrer sur l'évolution de la place de l'acteur humain et du combattant

dans les opérations militaires du 21 ème siècle et sur le rôle qui lui incombe. On peut supposer que les développements technologiques significatifs du dernier quart du siècle dernier, ne vont pas seulement continuer au cours de ce siècle mais vont encore s'accélérer. En conséquence, il existe et il est impératif de bien identifier les technologies clés qui auront un impact sur les opérations militaires du 21 ème siècle, et les facteurs émergents pour ensuite recommander une stratégie pour traiter ces problèmes.

Programme de la réunion

La réunion de spécialistes a été présidée par Mademoiselle Joanne MARSDEN (GB) et le Dr Didier BAZALGETTE (FR). Le comité chargé du programme était composé du Dr Ken BOFF (USA), du Prof. Berhard DOERING, du Dr Didier LAGARDE, du Dr Yvonne MASAKOVSKI (USA) de Mademoiselle Joanne MARSDEN et du Dr Didier BAZALGETTE.

Cette réunion a commencé par une session d'ouverture puis quatre groupes ont été formés avec mission de présenter un rapport des travaux. Une synthèse technique a ensuite eu lieu avant un discours programme de clôture.

Les conférences d'introduction ont été faites par le Dr J.L. POIRIER (Conseiller Facteurs humains du directeur du service de santé de l'armée de terre française), par le Prof. J-P. DALY (Directeur de l'hôpital d'instruction des armées du Val de Grâce, DCSSA) et par le Dr C. WIENTJES (Administrateur de la commission RTO-HFM). La session d'ouverture a été conclue par un discours programme du Prof. J-P. MENU (FR), de l'Air Commodore PEACH (GB) et du Dr N. GERSHON (USA).

Chacune des sessions des groupes a commencé par deux interventions dont le but était de lancer la discussion. A la fin de la journée, chacun des groupes était chargé de présenter le résumé des travaux du jour. A la fin de la réunion de spécialistes, chaque groupe a ensuite présenté le résultat global de ses travaux.

Le Prof. H. EGEA (FR) a présidé le premier groupe consacré aux ressources humaines et aux problèmes d'organisation (Session #A). Le Dr N. GERSHON (USA) a présidé le groupe chargé d'étudier les problèmes liés à la technologie et aux systèmes d'armes. (Session #B). Le Prof. P.PALANQUE (FR) était président du groupe consacré aux problèmes de communications (Session #D). Ensuite le Dr D. BAZALGETTE (FR) a réalisé la synthèse technique de la réunion de spécialistes et enfin le discours de clôture a été effectué par le Général B. d'ANSELME (FR).

La session de clôture a été animée par mademoiselle J. MARSDEN (UK), le Dr D. BAZALGETTE (FR), vice-président de la réunion et par le Dr D. LAGARDE (FR), coordinateur local de la réunion.

Evaluation technique

Discours programme du Professeur MENU

Dans sa présentation, le Prof. MENU a souhaité aborder les grands défis de la défense mais avec une approche non conventionnelle. Il semble que l'interdisciplinarité soit une des solutions possibles aux problèmes complexes associés au nouveau contexte qu'a entraîné la révolution dans les affaires militaires (*RMA revolution of military affairs).*

L'interdisciplinarité est un critère qui doit être pris en compte très tôt pour définir l'assise culturelle sur laquelle les savoirs techniques spécifiques peuvent être greffés. Cette approche est à l'opposé de celle qui, s'appuyant sur des formations monolithiques ne parviennent à créer, par juxtaposition, qu'une démarche seulement pluridisciplinaire.

De même, il apparaît souhaitable d'utiliser des modes de pensée plus productifs qu'une simple approche cartésienne rigide, qui ne s'intéresse, ne maîtrise ni ne manipule, les aspects dynamiques des systèmes complexes. Une telle approche basée sur la pensée complexe, au sens d'Edgar Morin, pourrait à la fois aider à l'élaboration et à la conduite des grands programmes de systèmes de défense, à la spécification des organisations mais aussi à la conduite des décisions à un niveau stratégique ou opératif dans les opérations politico-militaires.

Ainsi, bien à l'opposé de la tradition occidentale, et plus encore française, de pensée, de raisonnement et d'action basée sur le découpage, il semble que l'alternative basée sur la pensée complexe, soit une solution permettant de sortir des impasses dans lesquelles beaucoup de problèmes actuels sont venus se bloquer.

La pensée complexe induit et justifie *de facto* la répartition des informations vers une organisation interdisciplinaire, capable d'agréger et de faire émerger le savoir et le sens, dans un contexte dynamique et incertain.

C'est en s'appuyant sur des hommes interdisciplinaires de par leur formation, leur culture et leur mode de pensée qu'une telle approche pourrait constituer une ouverture vers de nouveaux paradigmes.

Discours programme de l'Air Commodore PEACH (GB*)*

Le deuxième orateur a fait le point sur l'influence que pouvait avoir le nouveau contexte stratégique sur quelques besoins militaires de base. Cette présentation a mis l'accent sur des questions très ouvertes et cruciales.

L'exercice du commandement, un des problèmes majeurs des opérations multinationales, est toujours dépendant de l'environnement culturel et parfois technologique. Ce fait incontestable conduit à s'interroger sur des notions telles que l'autonomie de commandement. La prise en compte de ce fait dans les organisations et dans la conduite des opérations et ce, dans les différents contextes culturels des acteurs impliqués, devient une condition essentielle de réussite.

Il s'agit d'un défi bien réel et il est nécessaire d'établir de nouveaux critères de recrutement, d'entraînement et de maintien de compétence pour des personnes susceptibles

d’utiliser des systèmes qui n'existent pas encore et dont les logiques ne sont pas encore bien définies. (Comme, par exemple, les futurs grands systèmes d'UAV).

Enfin le Commodore PEACH a souhaité amorcer une réflexion sur une question de haut niveau et très interdisciplinaire : Qui y a-t-il derrière le concept de "génie miliaire" proposée par CLAUSEVITZ ?

Discours programme du Dr GERSHON (USA)

Avec une approche moins conceptuelle et en analysant l’environnent quotidien à travers le regard d’un spécialiste des facteurs humains, le Dr GERSHON a commencé sa présentation par une question quelque peu provocatrice : Quel est l’avenir des facteurs humains si on ne les utilise que pour valider un déni du bon sens le plus élémentaire ? (*Is there a future for human factors if they are quite performed to deny the most elementary good sense* !)

Son premier constat est qu’il n’y a pas de complétude avec les outils et les méthodes du domaine. Faute de pouvoir formaliser certaines approches ou connaissances et faute de savoir évaluer ces éléments de pratique, une fâcheuse tendance se dessine à ne pas vouloir prendre en compte les éléments de pratique. Si ce fait est admis, est-ce une raison suffisante pour ne pas s’y intéresser ?

Le Dr GERSHON a ensuite proposé des orientations pour le futur autour de quatre idées principales *:*

Tous les développements et en particulier ceux concernant les interfaces homme-machine (MMI) entraînent des conventions nouvelles et socialement constructives *(All developments, and particularly MMI, induce new socially constructive interpretative conventions).*

Il est souhaitable de continuer à faire preuve de bon sens (mais la communauté FH devra réserver cette formulation à un usage interne au risque de voir assimiler, et réduire à nouveau, l'ergonomie et les facteurs humains au simple bon sens).

Il est nécessaire aussi d'accrocher le cœur des utilisateurs par un contenu affectif des interfaces homme machine *(The importance of the affect in MMI).*

Il est indispensable enfin de garder le contact avec les utilisateurs mais se pose alors un problème de logique industrielle car il existe une écart important, en particulier dans les grandes structures, entre le client et le donneur d'ordre.

Conférence de clôture du général d’ANSELME

Dans sa présentation de clôture, le Général d'ANSELME a insisté sur le fait que si de nos jours le combattant n’est pas radicalement différent de son homologue des guerres napoléoniennes, les jeunes générations sont davantage issues d’un milieu urbain que rural. Elles sont moins rustiques et donc moins endurcies que leurs aînées et on peut penser que les hommes soient plus fragiles et donc moins bien préparés pour l’action.

Mais ce qui a radicalement changé, c'est l'environnement et les moyens utilisés au combat. On peut parler d'un bouleversement complet et même d'une révolution intellectuelle et culturelle.

Les conséquences pour le combattant sont très importantes, non seulement parce qu'il doit s'adapter en permanence et de plus en plus rapidement . Il lui est demandé d'être de plus en plus fort, surtout en raison du niveau d'excellence requis en matière d'efficacité, de résistance, de connaissances, de motivation et de stabilité émotionnelle. Tout cela le rend bien évidemment psychologiquement plus vulnérable et accroît le risque de voir ses facultés d'adaptation diminuer.

L'ensemble des facteurs humains doit donc être placé au coeur des expressions de besoins militaires et ceci prouve sans conteste que la place de l'homme est plus que jamais essentielle dans la définition des outils militaires.

Les différents groupes de travail

Ressources humaines et problèmes d'organisation

Quatre présentations ont été effectuées au sein de ce groupe de travail.

Celle réalisée par le Prof. EGÉA (FR) (Comment réaliser un management par les contradictions ; document #13 *)* a permis de montrer comment la pensée complexe (complex thinking) pouvait être utilisée pour traiter des problèmes de management. C'est d'ailleurs en appliquant les concepts et la méthodologie de la pensée interdépendante que les travaux du groupe ont été conduits.

Le Dr BRY *(*Simulation d'exploitation opérationnelle et conception des organisations futures ; document #4) s'est d'abord positionné sur une approche épistémologique pour donner un sens aux fondements même de la simulation et de la conception centrée sur l'utilisateur. Il a ensuite présenté le concept des illustrateurs d'expression de besoin d'exploitation opérationnelle (IBEO) comme un moyen de spécifier, évaluer et qualifier les nouveaux métiers et les nouvelles organisations dans les futurs programmes navals.

Le Dr VON BAYER (Analyses des tâches, entraînement et simulation pour des opérations autres que la guerre ; document #5) a soulevé le problème de l'analyse d'activité, de la formation et de la simulation des Opérations autres que la guerre (Operations Other Than War OOTW). En effet, les OOTW impliquent d'autres activités que celles traditionnellement attribuées aux militaires. La réalisation de ces missions nécessite des connaissances nouvelles : politiques, sociales, ethniques. Elles peuvent comporter aussi des activités fort éloignées de la tradition militaire comme les discussions ou négociations.

Ce changement de paradigme oblige donc à réviser d'abord les méthodes d'observation, d'analyse d'activité et de retour d'expérience pour tenir compte de la complexité et la dynamique imbriquée des différents systèmes.

Il oblige aussi à repenser les contenus et les méthodes de formation et là aussi comme dans la présentation du Dr BRY, l'approche interdisciplinaire apparaît indispensable.

Des travaux du groupe, il est ressorti que la simulation des organisations et de leurs activités est nécessaire car elle a une incidence sur le choix des spécifications d'organisations, des éléments techniques et sur l'architecture des systèmes ainsi que sur la formation. Il faut également que cette simulation des acteurs et de leurs activités puisse avoir une valeur écologique.

Dans ce contexte, le concept du « capteur humain » peut être utilisé, car il peut être observé (avec des méthodologies appropriées lorsque il est acteur dans le système socio-technique complexe). Cette observation est alors un indicateur du fonctionnement certes de lui même mais aussi et peut être surtout du fonctionnement des organisations et du système.. Au cours de la discussion, les opérations avec des forces multinationales sont apparues comme un bon exemple de système socio-technique. En effet :

- Les caractéristiques techniques et organisationnelles des systèmes dépendent des critères culturels définis dès le stade de la conception ;
- Les concepts, doctrines et modes de commandement ou de management des hommes sont différents d'une nation à l'autre ;
- Par nature, la différence des langues et des cultures limite la communication entre les parties.

Il est donc nécessaire de disposer, à terme, de nouvelles possibilités en matière de management, de technologies ou de moyens d'interaction, et de compétences et méthodes d'entraînement.

En accord avec la dynamique des systèmes, tout système socio-technique doit être bâti autour de l'opérateur humain. Ce dernier ne doit plus être positionné dans le système comme un servant de matériel mais comme un exploitant de moyens divers lui permettant d'exercer ses talents d'une façon optimale. Grâce à une véritable interdisciplinarité et une approche véritablement intégrée des ingénieries de l'homme et des systèmes, il sera alors possible de créer des systèmes centrés sur l'homme **et** sur la technologie.

Enfin et en écho à la présentation de l'Air Commodore PEACH, la présentation de M. C. M. ABRAM (développement d'un principe d'évaluation basé sur Internet pour la sélection des personnels des trois armées ; document #17) a fait état d'une utilisation possible de la toile comme média de sélection mais aussi comme moyen de recueil d'informations destinées à alimenter des bases de données.

L'approche semble pertinente dans la mesure ou la toile devient un outil usuel qui permet de s'affranchir des difficultés des systèmes classiques de sélection. Cependant, malgré l'aspect idyllique de ce nouveau support médiatique, force est de reconnaître qu'il présente encore beaucoup de limites voire de défauts dont on ne peut s'affranchir que par une prise de conscience de l'écart existant entre la réalité et le souhaitable.

Problèmes liés à la technologie et aux systèmes d'armes

Ce groupe de travail a centré ses travaux sur les relations entre l'homme et les systèmes automatiques, considérant que c'est sur ce point essentiel que se concentrent les rapports entre l'homme et les système d'armes. Il va aussi de soi que cette approche n'est pas exclusive aux

systèmes d’armes mais se retrouve dans tous les systèmes socio-techniques complexes faisant appel à des automates.

Les problèmes récurrents ont été également abordés. Dans sa présentation (Conception des automatisations et systèmes à tolérance d’erreurs ; document 14) le Prof. AMALBERTI a remis en cause la réalité des gains obtenus, en matière de sécurité, par les environnements fortement automatisés.

Un cadre conceptuel s'appuyant à la fois sur le modèle de RASMUSSEN et sur un modèle de contrôle de sûreté écologique de la situation a été présenté. Les quatre origines chroniques des problèmes de facteurs humains liés à l'automation ont, dans ce cadre, été passées en revue:

- La faible perception de l'état du système ;
- La méfiance à l'égard des systèmes ;
- L'augmentation du niveau de risque accepté ;
- Les ambiguïtés dans la prise de responsabilité homme vs. automate.

Des solutions ont été proposées notamment en direction de stratégies plus sûres sur le plan écologique. Il a été, par ailleurs, signalé que les nouveaux systèmes (inhabités notamment) nécessiteront une vision systémique pour préciser le partage d'autorité dynamique entre l'homme et les automates.

Le problème de l'incertain dans l'environnement militaire a été abordé en particulier au travers de la présentation de Mr TAYLOR: (document #18 : technologies pour supporter le contrôle cognitif humain) *(Technologies for Supporting Human Cognitive Control).*

L'objectif de la méthode proposée est de fournir des éléments de réponse aux points suivants :

- Comment augmenter à la fois les données et l'information ?
- Comment l'homme doit-il comprendre de manière intuitive les informations contradictoires, incomplètes et incertaines tant au niveau des données que de l'information ?
- Comment la machine et l'automate peuvent-il faire de même ?
- Comment spécifier, valider et maintenir une architecture et des moyens de contrôle cognitifs ?
- Comment réaliser des automates, et des interfaces, qui se puissent se re-configurer suivant le contexte et les activités de l'opérateur ?
- Enfin comment sélectionner et former les futurs nouveaux opérateurs à ces modes de pensée à l’opposé d’une activité fortement basée sur les règles *(rule based*) qui est encore l'apanage de nombreux systèmes de défense ?

Il est probable que la démarche proposée par le Dr SOLLER et Mme SHOUVY (document #7). Conception itérative s'appuyant sur des simulateurs opérationnels pour la définition des interfaces des collecticiels) soit une des pistes à suivre.

Sur le plan méthodologique, en effet, cette approche est similaire à celle proposée par le Dr BRY. Elle préconise le développement de simulateurs opérationnels, instrumentés pour

étudier la tâche, le système et l'activité de tous les acteurs pour avoir, à terme, une meilleure connaissance et établir de meilleures spécifications. La valeur écologique d'une telle démarche semble bien réelle dans la mesure où elle utilise des acteurs humains très proches des acteurs futurs probables. Si de plus elle s'appuie sur des méthodologies apportant des corrections aux inférences établies, elle permettra de concevoir des systèmes futurs acceptables, autrement que ex-nihilo, ou au mieux à partir d'un retour d'expérience faiblement formalisé et structuré. Enfin l'approche utilisant des connaissances issues de domaines non nécessairement voisins mais dont la distance est quantifiable, pourrait permettre de nourrir de manière simultanée chacun des systèmes. Les travaux réalisés dans le contrôle aérien civil (i.e. la situation présentée dans ce papier) ou dans l'automobile font partie des exemples qu'il conviendrait de regarder sous cet aspect.

En présentant les récentes avancées dans le domaine de la technologie des dispositifs virtuels en matière d'imagerie rétinienne directe et affichages virtuels (document #6) *(Direct Retinal Imaging and Virtual Displays),* le Dr JONES a montré que si cette technique présentait un grand intérêt potentiel en terme d'application, certaines limitations technologiques étaient toujours présentes et la capacité de l'œil à moduler la lumière entrante par modification de la taille pupillaire demandait en retour une modulation de la source.

Problèmes médicaux

Quatre présentations ont été effectuées dans ce groupe de travail. Elle ont abordé des sujets qui, en première analyse, pouvaient paraître assez éloignés les uns des autres mais qui se sont révélés être à l'origine de discussions interdisciplinaires et de conclusions très fructueuses.

Dans sa présentation "Intégration de l'expertise médicale dans la conception des applications médicales à distance (Integration of Medical Expertise in Design of Telemedical Applications" document #8), le Prof. CINQUIN a montré comment, dans le cas de l'hospitalisation à domicile et de la surveillance médicale de personnes âgées, il était possible d'effectuer une surveillance quasiment en temps réel, en prenant en compte les paramètres essentiels en provenance de capteurs du commerce, avec un traitement approprié de ces données. Ceci sans être obligé de placer un grand nombre de capteurs et sans nuire à la protection de la vie privée, (encadrée par des textes législatifs). Dans un autre domaine, la protection juridique des acteurs (médecins, chirurgiens, pilotes…) et des personnes et des biens impliqués dans leur actions (patients, population civile…) doit être prise en compte dans la conception des systèmes, des procédures et des moyens de retour d'expérience utilisés.

Sur le plan des interfaces des systèmes utilisés, il a été constaté que celles des systèmes à usage médico-chirurgical n'avaient pas un degré de maturité aussi élevé que celui des interfaces homme machine (MMI) du domaine aéronautique.

La préparation de mission telle que pratiquée en aéronautique par les pilotes pourrait devenir à terme une obligation technique et juridique pour les actes chirurgicaux. Il convient donc de développer dans le domaine médico-chirurgical les outils, et tout particulièrement les bases de données, qui seront indispensables pour conduire ce type de préparation.

Pour ce qui concerne les aspects de protection contre les situations critiques, il est apparu nécessaire de développer des moyens technologiques supplémentaires pour assurer une

surveillance des personnes concernées. De manière plus générale, pendant les situations nominales de fonctionnement il semble nécessaire de développer aussi un système de surveillance permettant de gérer au mieux la composition des gaz respiratoires (plongée, aéronautique).

Dans sa présentation (Plongée, sortie de sous-marins et sauvetage, document #15), le Médecin Commandant GLOVER a insisté sur le fait qu'en matière de secours et de sauvetage en cas d'accidents de plongée ou à bord de sous-marins, l'organisation des secours et la capacité à agir en urgence sont aussi importantes que les technologies et les équipements utilisés.

Cet objectif rejoint celui présenté par le Prof. CINQUIN pour lequel, milieux et situations exceptés, les exigences restent les mêmes : éthique médicale, vie privée et instrumentation "transparente" de l'environnement par exemple.

Le problème de la simulation et de la préparation demeure identique que ce soit pour les problèmes médicaux ou aéronautiques (cf. communication # 10) : celui d'une simulation avancée difficile à réaliser avec, en corollaire une simulation plus légère qui devient trop simplifiée. Il s'agit de trouver le compromis optimal entre fidélité et pertinence pour utiliser des simulations les plus simples capables de développer des réflexes utiles en situation réelle et capables d'améliorer les connaissances sur les causes de défaillances.

Enfin, le domaine des biotechnologies a été abordé (Dr. NICKLIN, document #19 : l'impact futur de la biotechnologie sur les facteurs humains), sujet qui, à lui seul pourrait faire l'objet d'une réunion complète en raison des nombreux développements récents et de la forte activité dans ce domaine.

De nombreuses pistes technologiques existent et vont permettre de développer des capteurs pour surveiller l'homme, son environnement, et les incidences de l'action militaire sur l'environnement. La surveillance des risques de santé publique (surveillances des maladies endémiques par exemple) pourrait aussi bénéficier de ces technologies.

Néanmoins, un certain nombre de questions persistent:

- Le domaine militaire doit-il et peut-il attendre les développements civils ?
- Qu'en est-il des aspects éthiques et légaux? Si l'approche du Prof. CINQUIN est pertinente à petite échelle, peut-on la généraliser tant sur le plan technique que logique à des observations multifactorielles de grande envergure?

Des travaux du groupe, s'est fait jour l'existence de problématiques similaires en aéronautique, en particulier l'aviation civile, et dans la médecine et la chirurgie. Ces similitudes concernent autant les points techniques que les contraintes de réalisation de ces métiers: les aspects capteurs, la sécurité (zéro erreur imposée), les scénarios, l'entraînement, la perte de compétence, la culture (Cf. communication #10). Cette constatation pose clairement l'intérêt d'un échange d'expertise entre ces deux domaines.

Enfin, et lors d'actions d'équipes géographiquement et culturellement réparties, dans un contexte médico-chirurgical ou dans un contexte de communication air/sol il a été souligné l'importance des communications entre acteurs (hommes ou machine).

En dépit des différences de langue, de culture et de média il est indispensable de partager des modèles mentaux similaires sur toutes les dimensions utiles du problème traité.

Problèmes de communications

En s'appuyant sur ses travaux de recherche et sur des réalisations, essentiellement dans le domaine de la sécurité civile, le Prof. PAVARD (document #10 : le travail en coopération à l'aide de la conception par ordinateur) *(Design computer supported cooperative work -CSCW-applications)*, a présenté ses réflexions sur les applications dans le domaine des communications implicites dans les systèmes collaboratifs.

Il est apparu qu'une approche méthodologique rigoureuse, basée sur une analyse fine de l'activité permet de les identifier. Le cadre théorique développé permet ensuite de les formaliser. Ainsi, l'activité implicite qui existe dans ces systèmes est non déterministe par nature mais structurellement nécessaire pour accomplir des tâches dans un environnement complexe.

Pour ce qui concerne la spécification des interfaces, le Prof. PALANQUE a montré (document #20 : Des approches formelles pour des systèmes interactifs fiables et utilisables) comment il était possible de mettre en place une méthode formelle qui permette sans rupture de logique et sans introduire d'incertitude, de passer des éléments de spécification à la réalisation et à l'intégration des éléments d'interfaces ainsi produits au sein de plus vastes programmes.

Cet outil trouve son application dans deux problématiques particulières:

- Celle de pouvoir introduire des règles d'ergonomie du logiciel lors de toutes les phases de la spécification à l'implémentation validée ;
- Celle de pouvoir être utilisée comme un outil de modélisation pour les tâches réalisées en coopération par différents acteurs qu'il s'agisse d'opérateurs humain ou de systèmes techniques.

De l'ensemble des travaux du groupe, il est ressorti, en s'appuyant sur la communication du Lt Col. BONNER (document #16 : effets des facteurs culturels et leur intégration dans les futures opérations militaires) *(The Effects and Integration of Cultural Factors Within Future Multinational Military Operations)* que les opérations multinationales étaient un modèle pour les aspects communication, organisation, prise de décision dans lequel les spécificités de tous ordres pouvaient s'exprimer.

Ces éléments de spécificités sur lesquels un arrangement doit être effectué nécessite une double approche :

- Celle de la neutralisation d'abord pour permettre aux acteurs de différentes cultures de s'exprimer et de se comprendre dans des modalités, dans un langage et sur des concepts au moins partagés et au mieux devenus non-culturels.
- Celle de l'exploitation ensuite afin de valoriser, selon chaque culture, les points de force et d'efficience propres à chacune.

Pour ce qui est des équipes, et du fait des rotations nationales dans les différentes opérations, il sera nécessaire de construire des organisations souples, capables de supporter, sans perte de résultat, les changements induits par les relais mis en place entre les différentes nations.

Dans ce cas, les notions d'activités implicites et informelles seront à préciser. Seront-elles un frein à cette flexibilité ? Seront-elles un des moyens pour la rendre possible ? De toute façon, la formation à tous les niveaux restera un passage obligé, et encore plus nécessaire dans les opérations multinationales pour comprendre les systèmes et les hommes.

La boucle « Observation, Orientation, Décision et Action *(OODA)* deviendra, elle aussi, un sujet d'études mais aussi d'innovations dans le cadre de nouveaux systèmes.

En plus des aspects développés précédemment tels que formation, coopération des acteurs, coordination des équipes, le Dr ESSENS (document *#11* : Commandement futur) a montré comment des éléments technologiques novateurs et encore peu utilisés tels que le son 3D et l'affichage en perspective 3D pour représenter des données appropriées, n'impliquent pas la production d'une copie du réel. Ces affichages seront développés dans leurs aspects technologiques mais surtout dans leur logique d'utilisation.

Les nouveaux systèmes tels que véhicules non pilotés (qu'ils soient terrestres ou aériens) seront probablement les premiers bénéficiaires de telles interfaces, novatrices sur le plan technologique mais également sur le plan de la multimodalité. L'absence d'histoire et d'expérience permettra des avancées rapides et n'obligera pas à une avancée à petits pas dans la crainte d'une perte des acquis culturels ou de savoir faire.

Conclusion and recommandations

A l'issue des travaux des différents groupes, plusieurs axes ont pu être dégagés.

- Il existe des domaines qui sont identifiés comme prioritaires pour les aspects facteurs humains et qui sont insuffisamment couverts.
- L'interdisciplinarité semble être une des clefs de la réussite des facteurs humains dans le futur, particulièrement en ce qui concerne l'homme dans les systèmes socio-techniques complexes.
- Le soutien médico-chirurgical et les facteurs humains pourraient bénéficier l'un et l'autre d'échanges de méthodologies, d'expertises et de compétences.
- Sur le plan opérationnel, les travaux de plusieurs groupes ont spontanément convergé vers les opérations internationales qui sont maintenant, la plupart du temps, des opérations autres que la guerre (OOTW *Operations Other Than War).*
- Enfin une réflexion épistémologique doit être amorcée dans ce domaine car c'est sur un tel substrat que naîtront de nouveaux concepts ou paradigmes à la portée des facteurs humains.

Les priorités vis-à-vis de la recherche

Sur la base des travaux des différents groupes et de leurs présentations, il a été possible de proposer une représentation graphique des domaines dans lesquels une tâche importante reste à accomplir.

Deux axes ont été plus particulièrement identifiés: celui du niveau de priorité et celui du niveau actuel de ressources et de recherche.

Il apparaît que les opérations multinationales semblent être le domaine principal justifiant et nécessitant bon nombre de recherche en facteurs humains. La réussite de ces opérations reste très liée à l'Homme mais il semble pourtant que peu de travaux soient actuellement en cours selon une méthode globale, dynamique et intégrée.

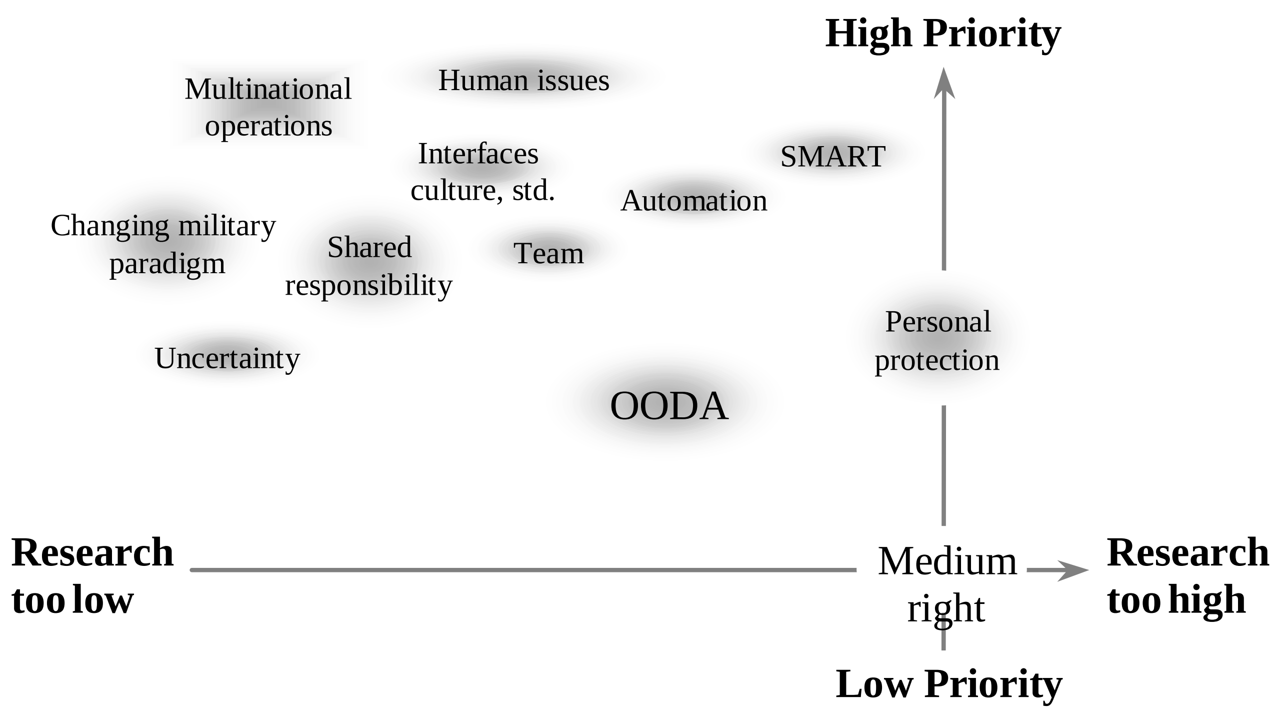
La réponse aux aspirations morales, sociales et de bien-être légitimement exprimées par les individus, même lorsque leur action se situe dans le domaine militaire, doit être prise en compte et satisfaite durant et en dehors de l'exercice de son activité militaire.

Le changement de paradigme militaire avec ses dimensions organisationnelles et opérationnelles doit être abordé et les spécialistes du domaine facteurs humains peuvent apporter des éléments de réponse.

Les facteurs humains pourraient aussi devenir les facilitateurs d'une discussion globale dans laquelle seraient impliqués tous les acteurs du domaine, allant du politique à l'opérationnel en impliquant au passage le milieu industriel sur lequel ces évolutions vont avoir un impact lors de la réalisation des systèmes futurs.

L'effort doit aussi être amplifié dans le domaines des interfaces homme machines (MMI), déjà bien actif, pour obtenir une réponse avec une conception centrée sur l’homme et s'appuyant sur les rapides évolutions technologiques.

Etant donné l'évolution du contexte et l’obligation absolue de résultats, le domaine médico-chirurgical, dans lequel ce souci est faiblement présent, pourrait tirer bénéfice de ces approches



L'interdisciplinarité

L'interdisciplinarité constitue une approche nouvelle qui peut probablement concerner l'ensemble des problèmes. Culturellement habitués que nous sommes à une solution des problèmes basée sur un découpage de niveau granulaire de plus en plus faible, on a longtemps pensé que la ré-agrégation des solutions locales fournirait, in fine, une réponse satisfaisante au problème global posé.

Si certains domaines peuvent se satisfaire de cette approche, celui des facteurs humains qui se situe dans un contexte de système socio-technique complexe et qui concerne des activités se déroulant dans des environnements difficiles à définir (dynamique, dégradé, ambigu, avenir incertain) ne paraît pas pouvoir répondre au problème posé. La phrase de SAINT EXUPERY soulignant que "Les hommes ont fait l'essai des valeurs cartésiennes, hors les sciences de la nature, ça ne leur a guère réussi" s'y applique parfaitement.

L'interdisciplinarité, avec comme fondement culturel une transversalité entre les éléments de connaissances pourrait être une des solutions permettant de répondre à ces importants besoins.

La pensée complexe, par sa capacité à traiter le problème dans son ensemble et de manière dynamique pourrait être le complément actif capable de manipuler, d'exploiter et de valoriser la connaissance dans une approche interdisciplinaire.

Une évolution se fait sentir dans le domaine des facteurs humains et de la médecine

Le domaine médico-chirurgical va être confronté à des exigences juridiques sans cesse croissantes. Ces exigences seront bien entendu identiques dans le domaine civil et militaire. La dualité de la problématique n'implique pas pour autant qu'il revienne au seul monde civil d'apporter sa contribution. Le monde militaire peut apporter des éléments de réponse appropriés en raison des situations extrêmes et très imbriquées avec des systèmes socio-techniques complexes.

En s'inspirant de la logique de préparation et de simulation de mission, couramment utilisée en aéronautique, il serait possible de mieux préparer les interventions chirurgicales et, sur la base de banques de données qu'il reste à établir, mieux préparer les décisions, les choix techniques et avoir une meilleure appréciation des risques et des bénéfices.

Dans un contexte culturel où les problèmes juridiques ont tendance à se développer et où le domaine de la santé est par essence tenu à une logique de « aucune erreur », il est probable que la connaissance et la décision seulement basée des heuristiques fortes des acteurs ne suffira bientôt plus à garantir en plus de la réalisation correcte de leurs actes, leur protection en cas d'incident ou d'accident.

La logique de formation et de maintien d'expertise utilisée en aéronautique pourrait, au travers d'une lecture adaptée, apporter des éléments de réponse à ce problème. Les interfaces des systèmes d'instrumentation médico-chirurgicaux pourraient bénéficier de la logique des approches et des savoirs acquis là aussi en aéronautique.

Enfin les travaux préparatoires de télésurveillance médicale civile pourraient fournir des éléments de réponse tant au délicat problème, en terme d'éthique, de protection de la personne qu' en terme de logique technique pour objectiver un niveau d'activité ou d'efficience que pour pouvoir éventuellement assurer un monitorage médical en cas de blessures.

Là encore, l'interdisciplinarité et le croisement des cultures et des connaissances sera le point de départ d'une solution porteuse.

Les opérations multinationales

Ce type d'intervention tend à se généraliser et rares seront les opérations militaires effectuées seulement par une seule Nation. De plus le bilan des opérations dans lesquelles les forces armées sont intervenues depuis la fin de la guerre froide fait apparaître une augmentation du nombre d'actions de type OOTW.

Dans ce contexte, la multiplicité mais aussi et surtout la nouveauté des problèmes auxquels sont confrontées les forces sont telles que l'on peut les considérer comme un bon "modèle" pour l'expression des besoins et des moyens futurs pour les facteurs humains à l'aube du 21ème siècle.

En effet, tout concourt à faire de ces missions "Le laboratoire" des facteurs humains de demain à commencer par l'étape de sélection et de préparation qui doit tenir compte des aspects particuliers de ces missions en matière de culture, de langage, d'éthique forcément différents entre les acteurs.

Par la multiplicité des systèmes socio-techniques complexes, d'origines industrielles et culturelles diverses, dont il faut impérativement assurer l'interopérabilité via la technologie ou via, en dernier recours, la communication entre les hommes, les missions OOTW constituent un moyen de mieux mettre l’homme en valeur dans une recherche d’une meilleure efficacité des missions.

Certes, la prise en compte de toutes les données sera difficile et à titre d'exemple, la simple notion de communication implicite ne sera pas la plus simple.

Dans ce contexte de nombreuses questions vont se poser :

- Comment former et entraîner les groupes hétérogènes et ce à tous les niveaux de commandement ?
- Comment cette question sera-t-elle reçue, en raison de la différence culturelle, lorsque la formation sera destinée au commandement de haut rang ?
- Comment traduire en composantes d'organisation la prise en compte de la communication implicite et informelle qui s'avère être un élément de sécurité des systèmes ?
- Comment organiser toutes ces priorités dans des contextes politiques, culturels, sémantiques, techniques et financiers différents ?

Accepter et traduire concrètement l'ensemble de ces points constitue un challenge pour les cultures, les logiques et les systèmes militaires. Enfin, il ne faudra pas oublier un certain nombre de points que l'on pourrait qualifier d'impacts de la technique :

- Il sera nécessaire de garder le contact avec l'utilisateur final, ce qui ne manquera de poser un problème de logique industrielle car il existe un écart important, particulièrement dans les gros systèmes entre le client donneur d'ordre et le client utilisateur.
- L'opposition entre la notion de servant d'armes et celle d'acteur au sein d'un système complexe devra être renforcée (la première disparaissant), par une approche de la conception centrée sur l'utilisateur dans laquelle l'Homme en tant qu'acteur devient, en élevant son niveau d'abstraction, superviseur puis manager de systèmes.
- Enfin, il ne faut pas perdre de vue le fait que les utilisateurs des systèmes qui rentreront en service en 2010 seront issus d'une société imprégnée de jeux électroniques et de systèmes de visualisation. Ce point reste relativement ignoré car non encore traité et il faudrait pouvoir en tirer les conséquences.

Dans sa présentation de clôture, le Général d'ANSELME a tenu à rappeler que l'homme est placé au centre de l'action. Puisque il est vulnérable tant au niveau physique que psychologique ou psycho-affectif, il convient de bien le positionner en tant que facteur de cohérence de ces systèmes futurs.

Ainsi la réflexion centrée sur l'homme qui pourrait être effectuée dans le cadre d'opérations internationales pourrait devenir à la fois une raison et une des clef des évolutions de cette dynamique complexe.

<u>Une réflexion épistémologique doit etre engagée dans le domaine des facteurs humains *(An epistemological reflection must begin in Human Factors)*</u>

Parmi les résultats relativement inattendus de cette réunion de spécialistes, il faut noter un souci exprimé non seulement par de nombreux orateurs mais aussi par les rapporteurs de groupes de repositionner la réflexion sur l'avenir des facteurs humains, et à travers eux sur l'efficience des systèmes socio-techniques complexes avec des hauts niveaux de pensée et ce, bien au-delà des simples descriptions de méthodes

Le Prof. MENU a fait référence aux voies ouvertes par Edgar MORIN avec, comme méthode de mise œuvre, la présentation du Prof. EGEA.

Les besoins des nouveaux systèmes ont été ramenés à des problèmes de langage et de culture par le Commodore PEACH.

La simulation, et plus particulièrement celle des organisations avec l'Homme dans la boucle a été ancrée, par le Dr BRY, par une approche épistémologique dans une démarche globale de conception centrée sur l'homme.

La présentation par le Dr VON BAEYER des défis que constituent les opérations internationales a mis en relief, elle aussi, l'importance des concepts culturels, éthiques.

Le Dr GERSHON a, quant à lui, évoqué la place de l'affectif dans la définition et dans l'acceptabilité de ces systèmes. Ceci amène à penser qu'il existe inévitablement une couche culturelle et personnelle qui se traduit par des difficultés pour la mise en oeuvre de système ou pour l'intégration dans des organisations multi-nationales donc multi-culturelles.

Ainsi il paraît nécessaire de redéfinir les relations de l'Homme avec la technique dans un cadre de systèmes et d'organisations interdiciplinaires, multi-langages, multi-culturels, fortement dynamiques, ou plusieurs logiques coexistent et dont l'usage oblige à prendre des décisions en fonction d’un passé ambigu pour agir sur un futur incertain.

Technical Evaluation Report

Dr. Didier Bazalgette
DGA/DSP/DT/SH
Ministry of Defence
26, Boulevard Victor
00457 ARMEES FRANCE

Introduction

Representatives of NATO member nations, Partnership for Peace countries and non-NATO member nations met in Paris (Val de Grâce Hospital) from 11 to 13 June 2001, for a Specialists Meeting on ''Human Factors problems in the 21st century''. This meeting was particularly concerned with Human Factors problems which have appeared since what is known as the Revolution in Military Affairs (RMA) dating from the end of the Cold War.

The meeting was held in parallel with a workshop on decision making in the 21st century from 13 to 15 June 2001, organised jointly by the DGA (The General Armaments Delegation of the French Ministry of Defence), the ONRIFO (Office of Naval Research Field Office)and the company THALES.

Theme and overview

RMA has already had a profound impact on military operations concepts. The notion of massive confrontations between adversaries supported by cutting edge technologies has largely been replaced by the belief in future conflicts which are delocalised and associated with peace enforcement or peacekeeping measures.

In addition, thanks to technological advances in the fields of sensors and information and communications systems, as well as in nanotechnology and biotechnology, weapons systems will become increasingly intelligent. This opens up perspectives of quasi stand-alone military operations, with warfighters remote from the conflict zone and a tendency to migrate towards the virtual battlefield. At the other end of the spectrum is the perspective of a coalition of different countries, NATO, PfP and non-NATO member countries, able to deploy forces in conflict zones. In these types of operation, the difficulties arise from the multilingual and multicultural environments in which the forces are obliged to operate (and this applies both to members of the coalition and to the other forces present).

In other words, RMA will not only continue, it will accelerate and will inevitably have implications for military authorities as it will for individual warfighters and those in command of weapons systems and their platforms.

If we wish to look at the human factors issues which follow from this revolution in military affairs, we must concentrate on the changes which have occurred in the place of the human player and the warfighter in 21st century military operations and on his new role. We can assume that the significant technological developments of the last quarter of a century will not only continue, but accelerate during this century. As a result, it is vital that we should identify the key

technologies which will have an impact on 21st century military operations, and the emerging factors in order to recommend a strategy for dealing with these problems.

Meeting Programme

The Specialists Meeting was chaired by Miss Joanne MARSDEN (GB) and Dr. Didier BAZALGETTE (FR). The Programme Committee was composed of Dr. Ken BOFF (USA), Prof. Bernhard DOERING, Dr. Didier LAGARDE, Dr. Yvonne MASAKOVSKI (USA), Miss Joanne MARSDEN and Dr. Didier BAZALGETTE.

The meeting began with an opening session, following which four groups were formed with a mandate to present a report on the work achieved. This was followed by a technical summary and finally a closing address.

The introductory papers were presented by Dr. J.L. POIRIER (Human Factors consultant to the Director of the French Air Force Health Service), by Prof. J-P DALY (Director of the French Armed Forces Teaching Hospital Val de Grâce DCSSA) and by Dr. C.WIENTJES (Panel Executive RTO/HFM). The opening session concluded with a keynote speech by Dr. J-P MENU (FR), Air Commodore PEACH (GB) and Dr. N. GERSHON (USA).

Each group session started with two presentations designed to initiate discussion. At the end of the day, each group presented the results of the days work. At the end of the Specialists Meeting, each group then presented the final results of its work.

Prof. H. EGEA (FR) chaired the first group on human resources and organisational problems (Session #A). Dr. GERSHON (USA) chaired the group on technology and weapon systems related problems. (Session #B). Prof. P.PALANQUE (FR) chaired the group on communications problems (Session #D). Dr. D.BAZALGETTE then gave a technical summary of the Specialists Meeting and finally the closing address was made by General B. d'ANSELME (FR).

The closing session was chaired by Miss J. MARSDEN (UK), Dr. D. BAZALGETTE (FR), Vice Chairman of the meeting and by Dr. D. LAGARDE (FR), Local Coordinator.

Technical evaluation

Keynote speech by Prof. MENU

In his presentation, Prof. MENU decided to adopt a non-conventional approach to the major challenges in the field of Defence. Interdisciplinarity appears as one of the possible solutions to the complex problems associated with the new context introduced by the revolution in military affairs (RMA).

Interdisciplinarity is a criterion to be taken into account very early in the process of defining the cultural stem onto which specific technical expertise can be grafted. This approach is the opposite of that based on monolithic formations and which only manages, by juxtaposition, to create a multidisciplinary approach.

Similarly, it would seem advantageous to use more productive modes of thinking than that of a rigid Cartesian approach, which is neither interested in, nor understands nor is able to handle the dynamic aspects of complex systems. Such an approach, based on complex thinking in the sense intended by Edgar Morin, could help with the drafting and implementation of major defence system programmes, with the specification of organisations and also with the implementation of decisions at a strategic or operative level in politico-military operations.

So, contrary to the western, and in particular the french tradition of thinking, of reasoning and of action based on the breakdown of problems into their component elements, it would seem that an alternative solution, based on complex thinking, would provide a way out of the blind alleys in which many current problem solvers find themselves.

Complex thinking leads to and justifies *de facto* the dissemination of information to an interdisciplinary organisation, capable of combining knowledge and meaning and presenting them in a dynamic and uncertain context.

<u>Keynote speech by Air Commodore PEACH (GB)</u>

The second speaker focussed on the influence which the new strategic context could have on one or two basic military requirements. This presentation emphasized some very open and crucial questions.

The exercise of command, one of the major multinational operation problems, still depends on the prevailing cultural, and occasionally technological environment. This undeniable fact leads to the questioning of notions such as the autonomy of command. Allowance for this fact, in the organisation and conduct of operations, while also taking into account the different cultural contexts of the players involved, is becoming an essential condition for success.

This is a very real challenge and we need to produce new recruitment, training and competence preservation criteria for persons likely to be using systems which do not yet exist and for which logic schemes have not yet been properly defined. (As for example the future large scale UAV systems).

Finally, Commodore PEACH offered the following high level and highly interdisciplinary question as food for thought : ‘What is behind the concept of “Military engineering’ proposed by CLAUSEVITZ ”?

<u>Keynote speech by Dr. GERSHON (USA)</u>

Adopting a less conceptual approach and analysing the day to day environment through the eyes of a human factors specialist, Dr. GERSHON began his presentation with a rather provocative question : “What is the future for human factors if they are only used to validate a denial of the most elementary common sense ?”

His initial finding was that there is a lack of completeness with the tools and the methods used in this field. Because certain approaches and certain forms of expertise cannot be expressed formally and because we do not know how to assess these practical elements, there is a growing

and unfortunate tendency to ignore them. Although this may be the case, is that sufficient reason not to be interested in them ?

Dr. GERSHON then suggested a way ahead based on 4 main ideas :

All developments and in particular MMI, induce new socially constructive interpretative conventions

We should continue to exercise common sense (however the Human Factors community will have to keep this for internal use only, otherwise it will again see ergonomics and human factors being assimilated with and reduced to matters of simple common sense).

It is also necessary to win over the users by including some emotional content in the MMI's.

Finally, it is vital to maintain contact with users, although there is a problem of industrial logic here, as there is a considerable gulf, especially in large companies, between customer and originator.

<u>Closing address by General d'ANSELME</u>

In his closing presentation, General d'ANSELME stressed the fact that although today's warfighter is not radically different from his counterpart from the Napoleonic wars, the younger generation tends to come more from an urban than a rural background. They are less rustic and therefore not as tough as former generations and it might be thought that they are more fragile and less well prepared for action.

What has radically changed is the environment and the equipment used in combat. We could say that there has been a radical change, not to say an intellectual and cultural revolution.

The consequences for the warfighter are considerable, not only because he is obliged to constantly adapt and to do so ever more rapidly. He is asked to be better, in particular with respect to the level of excellence required in efficiency, resistance, knowledge, motivation and emotional stability. Naturally, all this makes him more vulnerable psychologically, and increases the risk of deterioration of his faculties of adaptation.

The whole of human factors should therefore be placed at the Heart of the expression of military requirements and this proves indisputably that the place of man is more than ever an essential part of the definition of military hardware.

<u>The different working groups</u>

<u>Human resources and organisational problems</u>

Four presentations were made in this working group.

The presentation by Prof. EGEA (FR) ("How to achieve management by contradiction" document #13) showed how complex thinking could be used to deal with management

problems. Moreover, the group applied the concepts and methodology of intrdependent thinking to carry out its work.

The presentation by Dr. BRY ("The simulation of operational working and the design of future organisations" document #4) first took an epistemological approach to give meaning to the foundations of user oriented simulation and design. It then presented the concept of Illustrators of the Expression of Operational Working Needs (IEOWN) as a way of specifying, evaluating and qualifying the new skills and the new organisations in future naval programmes.

The presentation by Dr. VON BAYER ("Task analysis, training and simulation for operations other than war" document #5) raised the problem of activity analysis, training and simulation of Operations Other Than War (OOTW).

Essentially, OOTW involves activities other than those traditionally assigned to military personnel. The performance of these missions requires new knowledge : political, social and ethnic knowledge. They may also include activities greatly removed from the military tradition such as discussion and negotiation.

This change of paradigm makes it necessary first of all to review methods of observation, of activity analysis and of feedback, in order to allow for the complexity and dynamics built in to different systems.

It also means that we have to rethink training methods and content, and here again, as in Dr. BRY's presentation, an interdisciplinary approach seems essential.

It emerged from the work of the group that the simulation of organisations and their activities is necessary, since it has an impact on the choice of specifications of different organisation systems and of technical elements as well as on the architecture of systems and on training. This simulation of the different players and their activities must also have some ecological value.

In this context, the concept of the "human sensor" can be used, as he can be observed using appropriate methodologies when he is a player in a complex socio-technical system. This observation is then an indication, not only of his own functioning, but also, and perhaps above all, of that of the organisation applied and of the system.. During the discussions, operations involving multinational forces appeared as a good example of a socio-technical system. Since :

- The technical and organisational characteristics of systems depend on cultural criteria defined at the design stage;
- The concepts, doctrines and modes of command or man management are different from one nation to another;
- By their nature, differences of language and culture limit communications between the different parties.

Therefore at some stage, we shall have to develop new capacities in management, technology, means of interaction, and training skills and methods.

In accordance with systems dynamics, any socio-technical system should be built around the human operator. The operator should no longer be positioned in the system like some kind of

hardware servant, but as the operator of a range of resources enabling him to exercise his talents in optimum fashion. With true interdisciplinarity and a truly integrated approach to systems and human engineering, it will at last become possible to create systems focussed on man **and** on technology.

Finally, and complementing the presentation made by Air Commodore PEACH, the presentation by M.C.M. ABRAM ("The development of an evaluation principle based on Internet for the selection of armed forces personnel" document #17) described the possible use of the Web as the medium of selection, and also as a means of gathering information in order to feed databases.

The approach seems pertinent to the extent to which the Web is becoming a common tool enabling the user to overcome the difficulties attaching to traditional selection systems. However, in spite of the idyllic aspect of this new medium, it must be said that it still has many limits and even defects which can only be resolved by the user recognising the gap between the desirable and the feasible.

Technology and weapon systems related problems

This working group focussed its work on the relationships between man and automatic systems, considering this to be the nodal point of man/weapon system relations. It is evident that this approach is not exclusive to weapons systems but can also be found in all complex socio-technical systems using automatic control systems.

Recurrent problems were also examined. In his presentation ("The design of automatic systems and fault tolerant systems" document #14) Prof. AMALBERTI questioned the reality of the security gains achieved by heavily automated environments.

A conceptual framework based both on the RASMUSSEN model and on a control model of the ecological safety of the situation was presented. The four chronic origins of human factors linked to automation were reviewed :

- Poor perception of system status
- Mistrust of systems
- Increased level of acceptable risk
- Ambiguities in the uptake of responsibility : man versus automat

Solutions were proposed, in particular in the sense of more reliable strategies from the ecological point of view. It was, moreover, pointed out that the new systems (notably the manned ones), require a systems analysis overview in order to determine the dynamic authority share out between man and automatic control systems.

The problem of the uncertain in the military environment was broached, in particular in Mr TAYLOR's presentation : (document # 18 : "Technologies for the support of human cognitive control"). The aim of the proposed method is to provide answers to the following points :

- How can we increase both data and information ?

- How is man to intuitively comprehend contradictory, incomplete and uncertain information both from the point of view of data and information ?
- How can machines and automatic control systems perform the same functions ?
- How can we specify, validate and maintain cognitive control architecture and resources ?
- How can we make automatic control systems and interfaces which can reconfigure themselves to suit the operator context and activities ?
- Finally, how can we select and train future operators in these modes of thinking as opposed to the predominantly rule based activities which are exclusive to many defense systems ?

The approach suggested by Dr. SOLLER and Mrs SHOUVY (document # 7 "Iterative design based on operational simulators for the definition of interfaces and groupware") is no doubt one of the avenues to be explored.

From the methodological point of view this approach is in fact similar to that proposed by Dr. BRY. It recommends the development of operational simulators, instrumented for studying the tasks, systems and activities of all the players involved, so as to ultimately provide a better understanding of what is happening and be able to produce better specifications. The ecological value of such an approach seems authentic to the extent to which it uses human subjects who are very similar to the probable future operators. If in addition, it is based on methodologies which enable correction of established inferences, it will enable the design of future systems which are acceptable other than in an *ex nihilo* way, or, at best, on the basis of a very loosely structured and formalised type of feedback.

Finally, the approach which uses knowledge from fields which, while not necessarily connected, are located at a quantifiable distance from each other, could provide simultaneous inputs to each of the systems. The work carried out in the civilian air traffic control area (i.e. the situation presented in this paper) or in the automobile industry are among the examples of cases worth looking at from this aspect.

In presenting recent progress in the technology of virtual direct retinal imaging devices (document # 6 "Direct Retinal Imaging and Virtual Displays"), Dr.JONES showed that although this technique was potentially interesting in terms of applications, some technological limitations remained and the capacity of the eye to modulate incoming light by modifying the size of the pupil required parallel modification of the source.

Medical problems

Four presentations were made in this working group.

They concerned subjects which, at first sight, seemed to be somewhat removed from each other, but which in fact produced some very fruitful interdisciplinary discussions and conclusions.

In his presentation on "The integration of medical expertise into the design of telemedical applications" (document # 8), Prof. CINQUIN showed how, in the case of home hospitalisation and medical surveillance of the elderly, it was possible to carry out surveillance in quasi-real time, using essential parameters supplied by off-the-shelf sensors, after appropriate processing of this data. This could be achieved without having to install a great many sensors and without intrusion on privacy (as defined in legislative texts). In another field, the legal protection of the

players involved (physicians, surgeons, pilots…) and of the persons and assets involved in their actions (patients, civilian population…) should be taken into account in the design of the systems, procedures and feedback devices used.

Concerning the interfaces with the systems used, it was noted that those used to interface with medico-surgical systems were not as mature as those used for MMI in the aeronautical field.

Mission rehearsal as practiced by pilots could eventually become a technical and legal obligation for surgical acts. Consequently, the tools and in particular the data bases essential to this activity should be developed in the medico-legal field.

With regard to protection against critical situations, it appeared necessary to develop additional technological resources to ensure surveillance of the persons concerned. More generally speaking, for nominal operating situations, a surveillance system for optimum monitoring of the composition of respiratory gases (diving, aeronautics), should also be developed.

In his presentation (Diving, exiting from submarines and rescue, document # 15), Medical Officer Surgeon GLOVER stressed that when dealing with search and rescue from submarines or diving accidents, the organisation of the rescue forces and the ability to act fast are as important as the technologies and equipment used.

This statement matches with that by Prof. CINQUIN, for whom, environment and situation apart, the requirements remain the same : medical ethics, privacy and “transparent” instrumentation, of the environment for example.

The problem of simulation and rehearsal remain identical whether for medical or aeronautical problems (cf. Presentation # 10) : i.e.that of an advanced simulation which is difficult to perform in corollary with a less demanding simulation which becomes too simplified. The aim is to find the optimum trade-off between fidelity and relevance in order to be able to use the simplest simulations capable of developing reflexes which are useful in a real situation and capable of improving our knowledge of the causes of failure.

Finally, the field of biotechnology was examined (Dr. NICKLIN, document # 19 : “The future impact of biotechnology on human factors”), which subject could on its own form the basis of a whole meeting, given the number of recent developments and the high level of activity in this field.

A number of avenues of technological exploration exist and these will eventually lead to the development of sensors for monitoring man, his environment and the impact of military action on the environment. The monitoring of public health risks (monitoring of endemic illness for example), could also benefit from these technologies.

Nevertheless, a certain number of questions remain :

- Should the military wait for civilian developments ?
- What about legal and ethical considerations?
- If the approach taken by Prof. CINQUIN is relevant on a small scale, can it not be extended, both from the technical and logical points of view to large scale multifactorial observations ?

The work of the group revealed similar problematics in aeronautics, particularly in civil aviation, in medecine and in surgery. These similarities concern both technical points and skill constraints: sensors, safety (zero error constraint), scenarios, training, skill loss, and culture (cf. Presentation # 10). This finding points clearly to the benefit of an exchange of expertise between these two fields.

Finally, the importance of communications between the different players (men or machines) was stressed during actions by geographically and culturally remote teams in a medico-surgical or an air-to-ground communications context.

In spite of differences of language, culture and media, it is vital to be able to share similar mental models of all the useful dimensions of the problem dealt with.

Communications problems

Basing himself on his research work and on achievements, essentially in the field of public safety, Prof. PAVARD (document # 10 “Computer design assisted cooperative work”), presented his thoughts on the communications applications implicit in cooperative systems.

It was shown that they could be identified by a rigorous, methodological approach, based on a fine analysis of activity. They could then be expressed formally using the theoretical framework developed. Thus, the implicit activity which exists in these systems is non-determinist in nature but structurally necessary in order to carry out tasks in a complex environment.

Regarding specification of the interfaces, Prof. PALANQUE showed (document # 20 : “Formal approaches to reliable and usable interactive systems”), how it was possible to implement a formal method which enabled transition from specification to production of interfaces and their integration into the most ambitious of programmes without any break in logic and without introducing uncertainty.

This tool finds its application in two particular problematics :

- That of being able to introduce software ergonomics rules at all stages of the specification of the implementation validated;
- That of being able to be used as a modelling tool for tasks carried out in cooperation by different players, whether human operators or technical systems.

It emerged from the overall work of the group, and with particular reference to Lt. Col. BONNER’s presentation (document # 16 : “The effects of cultural factors and their integration into future multinational military operations”), that multinational operations were a model for the communications, organisation and decision taking aspects, in which all types of specific elements could be expressed.

These specific elements require a dual approach :

- First, some neutralisation has to take place, in order to allow players from different cultures to express themselves and to understand each other with regard to methods and language and attempt to share concepts which hopefully would become non-cultural.

- Then, actual operation, in order to further enhance the strong points and the efficiency inherent in each culture.

As regards the teams, given the rotation of nationals around the various operations, flexible organisations will be required, capable of absorbing the changes brought about by the relaying system agreed by the different nations, without any loss of efficiency.

In this case, we shall need to define our concepts of implicit and informal activities. Will they put a brake on this flexibility ? Or will they be one of the means of making it possible ? At all events, training will remain a must and will be all the more necessary for multinational operations in order to understand men and systems.

The loop comprising “Observation, orientation, decision, action (OODA), will also be studied but with innovations regarding new systems.

In addition to the aspects developed previously such as training, cooperation of the players and coordination of the teams, Dr. ESSENS (document # 11 : “Future command”), showed how innovatory and as yet, little used technology elements, such as three dimensional sound and 3D perspective displays to represent relevant data do not involve making a copy of reality. These displays will be developed technologically but also from the point of view of user logic.

New systems such as UAV’s (either air or land) will probably be the first to benefit from such interfaces, which will be innovative both from the point of view of technology and of multimode capability. However, the absence of past history and experience in this field will enable rapid development, unlike the type of timid progress which comes from the fear of losing cultural experience and know-how.

Conclusions and recommendations

The work of the different groups resulted in the identification of several broad lines of action.

- Fields which are presently covered inadequately were identified as priorities for human factors research.
- Interdisciplinarity emerged as one of the keys to success in human factors in the future, particularly with respect to the place of man in complex socio-technical systems.
- Medico-surgical support and human factors could benefit from a mutual exchange of methodologies, expertise and capabilities.
- From the operational point of view, the work of several groups spontaneously converged on international operations, which are now generally operations other than war (OOTW).
- Finally, there is an epistemological avenue to be explored, as this is the kind of substrate which could produce new concepts or paradigms applicable to human factors.

Research priorities

The work of the different groups and their presentations were used to make a graphic display of the fields in which a significant amount of work remains to be achieved.

Two themes in particular were identified : priority levels and the current state of resources and research.

It would seem that multinational operations are the main field justifying and requiring a great deal of human factors research. The success of these operations remains closely tied to human capacities, although little work seems to be in progress in any global, dynamic and integrated way.

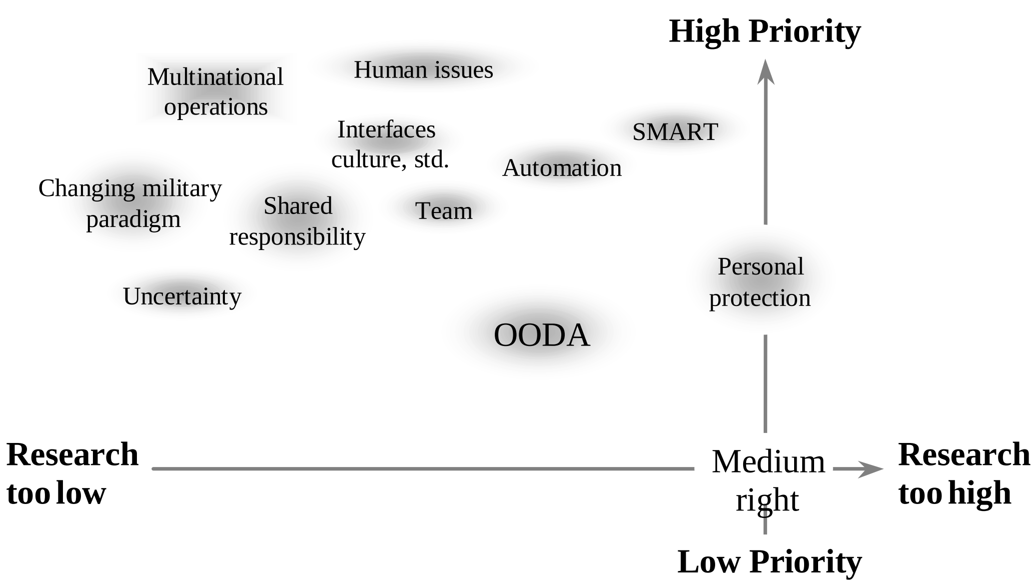
The response to the moral, social and welfare aspirations legitimately expressed by individuals, even when their action is in the military field, should be taken into account and provided for, both during and after the exercise of military activity.

A change in the military paradigm with its organisational and operational dimensions should be attempted and human factors specialists have a contribution to make.

Human factors could also become one of the enablers of a global discussion involving all the players concerned, from policy to operations, taking in the industrial sector which will be impacted by these developments when it comes to producing the future systems.

More effort should also be made in the field of MMI which is already active, so as to achieve human-oriented design based on rapid technological development.

Given the change of context and the absolute obligation to produce results, the medico-surgical field, which seems little concerned by the situation, could draw benefit from these approaches.



Interdisciplinarity

Interdisciplinarity constitutes a new approach which can probably be applied to all the problems discussed here. Culturally accustomed as we are to the breakdown of problems into increasingly

tiny elements, we have long considered that the recombining of local solutions would provide *in fine*, a satisfactory answer to the overall problem posed.

Although this approach may be adequate in certain fields, human factors, which operates in the context of a complex socio-technical system concerning activities carried out in environments which are difficult to define (dynamic, degraded, ambiguous and with an uncertain future), does not seem to be able to respond to the problem posed. The phrase by SAINT EXUPERY which states that “Men have tried the Cartesian value system. Apart from the natural sciences, it can hardly be said to have been a great success” is perfectly applicable here.

Interdisciplinarity, with its cultural foundation of transversality between elements of knowledge could be one of the ways of responding to these major demands.

Complex thinking, by its capacity to deal with a problem as a whole and in dynamic fashion, could be its active complement, capable of handling, using and enhancing knowledge through an interdisciplinary approach.

Major changes are afoot in human factors and medecine

The medico-surgical field will be confronted with ever increasing legal demands. These demands will, of course, be identical in both the civilian and military domains. However, the duality of the problematics means that it will not just be the civilian world which will be required to make a contribution. The military are able to provide relevant answers, due to the extreme situations which they encounter, which are highly interwoven with complex socio-technical systems.

Using the mission rehearsal and simulation logic currently exploited in aeronautics, it will be possible to improve the preparation of surgical interventions, and with databases yet to be created, better prepare decisions and technical choices and gain a better idea of the risks and benefits.

In a cultural context in which legal problems are tending to increase and where the health care sector is by its very essence held to a logic of “zero error” it is unlikely that knowledge and decision making alone, based on the strong heuristic convictions of the players, will any longer suffice to guarantee, in addition to the correct performance of their acts, their protection in the event of accidents or incidents.

The logic of training and expertise conservation used in aeronautics could, by means of suitable adaptation, provide an answer to this problem. Medico-surgical instrumentation interfaces could benefit from the logic of the approaches and experience gained in aeronautics.

Finally, the preparatory work carried out on civilian medical telesurveillance could provide answers to the difficult problem, both in ethical terms, of the protection of personnel, and in terms of technical logic, of the acquisition of objective information on activity levels and the possible provision of medical monitoring in the event of casualties.

Here again interdisciplinarity and the confluence of cultures and knowledge will be the starting point for a lasting solution.

<u>Multinational operations</u>

This type of intervention is increasingly common and it is rare to find a military operation carried out in isolation by a single nation. In addition, the records show an increase in the number of OOTW operations out of the total of operations involving armed forces since the end of the Cold War.

In this context, the multiplicity and, above all, the novelty of the problems facing the armed forces have been such as to be considered as a good “model” for the expression of future human factors requirements and resources at the start of the 21st century.

Indeed, everything seems to work in favour of making these missions the “laboratory” for human factors of tomorrow, starting with the selection and preparation stage during which allowance has to be made for the special nature of these missions in which culture, language and ethics are necessarily different from player to player.

Given the multiplicity of the complex socio-technical systems involved, with their different industrial and cultural origins, in which interoperability must be ensured via technology, or, as a last resort, by communication between men, OOTW missions provide a way of elevating man in the search for greater mission efficiency.

Naturally, it will be difficult to take account of all the data, and as an example the simple notion of implicit communication will no longer be simple.

In this context, a number of questions arise :

- How do we form and train disparate groups, and at all levels of command ?
- How will this question be received, owing to the difference in culture, by high ranking command ?
- How can we translate allowance for implicit and informal communication, which is an element of systems safety, into organisation components ?
- How can we organise all these priorities within different political, cultural, semantic, technical and financial contexts ?

Accepting and translating all these points is a challenge for the cultures, the logics and the military systems involved. Finally, we must not forget a certain number of points which could be qualified as technology impacts :

- It will be necessary to maintain contact with the end-user, who will certainly pose a problem of industrial logic, as there is a big gap, especially in large scale systems between the originator and the customer/user.
- The opposition between the notion of weapons servant and player in complex systems will need to be reinforced (since the first notion will disappear), by a user-oriented design approach, in which man as a player is able to raise his capacities for abstract thinking so as to become a systems supervisor and ultimately, a systems manager.
- Finally, we must not lose sight of the fact that the users of systems commissioned in 2002 will be drawn from a society imbued with electronic games and display systems. This point has been largely ignored and we should be ready to profit from it.

In his closing presentation, General d'ANSELME reminded the meeting that man is placed in the centre of the action. As he is vulnerable both physically and psychologically or psycho-affectively, he should be carefully positioned as a coherence factor in these future systems.

In this way, the man-centred study which could be carried out as part of international operations could become both one of the reasons for and one of the keys to the progression of this complex dynamic.

An epistemological study should be undertaken in the field of human factors

Among the more unexpected results of this Specialists Meeting was the concern expressed not only by a number of speakers but also by group rapporteurs, to recenter the discussion on the future of human factors, and to look at the efficiency of complex socio-technical systems with high levels of thinking, far exceeding simple descriptions of methods.

Prof. MENU referred to the avenues opened up by Edgar MORIN with, as an implementation method, the paper given by Prof. EGEA.

The requirements of the new systems were summarised as problems of language and culture by Commodore PEACH.

Simulation, and in particular the simulation of organisations with man-in-the-loop, was defined by Dr. BRY using an epistemological approach, in a global human-oriented design concept.

The presentation by Dr. VON BAYER on the challenges constituted by international operations also highlighted the importance of cultural and ethical concepts.

Dr. GERSHON discussed the place of the affect in the definition and in the acceptability of these systems. This points to the fact that there inevitably exists a cultural and personal layer, which reveals itself in the difficulties encountered in implementing a system, or in the difficulties of integrating into multinational and, therefore, multicultural organisations.

So, it would seem necessary to redefine the relationships between man and technique, in a framework of systems and organisations which are interdisciplinary, multilingual, multicultural, and highly dynamic, in which several logics co-exist and whose use means taking decisions on the basis of an ambiguous past in order to act in an uncertain future.

Systémique et pensée complexe
Enjeux pour l'ergonomie du XXI ième siècle

Jean-Pierre Menu
Professeur agrégé, Médecin en Chef, Directeur adjoint
Institut de Médecine Navale du Service de Santé des Armées
BP 610, 83 800 Toulon Naval
France

Pourquoi un tel titre ? Quel est l'objectif ?

La systémique et la pensée complexe sont deux concepts d'origine, de période d'apparition et d'utilisation différentes.

La systémique est bien connue depuis les années 1940. Elle est couramment utilisée par les ingénieurs et les chercheurs. Un système est un ensemble d'éléments en interaction dynamique, organisés en fonction d'un but.

La pensée complexe appartient au domaine de la philosophie. Bien que ce soit Pascal qui ait formulé que «Le tout est supérieur à la somme des parties», Edgar Morin a proposé ce paradigme il y a près de 30 ans. Il faut aborder tout problème dans sa globalité et sa complexité et ne pas le réduire à une somme d'analyses hyperprécises sur des domaines disjoints.

L'ergonomie depuis sa création, a pris une place, en un demi siècle, qui s'apparente aux spécialités définies au début du XIX siècle par Auguste Comte. Bien que s'intéressant à l'origine au travail de l'homme afin d'améliorer les conditions de travail, elle ne couvre plus aujourd'hui l'ensemble des problèmes soulevés par le travail et les systèmes sociotechniques complexes.

Les deux concepts que nous allons associer aboutissent au développement d'une approche multidisciplinaire étendue du travail. Ils autorisent aussi une vision plus globale des situations de travail dans lesquelles l'ergonomie s'intègre en temps que discipline d'intégration de spécialités diverses. Mais pour prendre en compte la complexité ou pour avoir une approche globale, l'application d'un paradigme d'Ergo-anthropologie conviendrait mieux. Construire et développer ce nouveau paradigme constitue l'objectif fixé.

Communication présentée lors de la réunion des spécialistes RTO HFM sur «Les facteurs humains au 21e siècle», organisé à Paris, en France, du 11 au 13 juin 2001, et éditée dans RTO-MP-077.

1 – L'homme au travail et le travail de l'homme

Il a fallu près de deux siècles depuis la classification des disciplines d'Auguste Comte, pour que divers courants de préoccupations sur l'homme au travail se rejoignent. Ce seront respectivement les ingénieurs et les scientifiques prenant en compte l'utilisation de la force physique de l'homme et de l'animal, les médecins et les hygiénistes dénonçant les ambiances et les conditions de travail défavorables à la santé, les physiologistes suivant les traces de Claude Bernard et de Paul Bert puis les psychologues qui s'intéresseront à l'homme, indépendamment de tous les travaux menés sur l'organisation du travail ou sur la sociologie du travail à la suite des travaux de Taylor, Max Weber….

Pour Karl Marx, le travail n'est pas une valeur mais une nécessité physique de la condition humaine, indépendante par cela même de toutes ses formes sociales mais plutôt également commune à toutes.

1 – 1 Adaptation du travail à l'homme

Le terme ergonomie a été utilisé en 1949, par Ken Murrell, ingénieur et psychologue gallois. Il a été préféré alors à un autre terme, ergologie, terme désignant la science du travail humain.

L'ergonomie a été définie initialement par une formule lapidaire: adaptation du travail à l'homme. Pour Etienne Grandjean, physiologiste qui a formé pendant des années à Zurich, des ingénieurs, "l'ergonomie est une science interdisciplinaire; elle comprend la physiologie et la psychologie du travail, ainsi que l'anthropologie et la sociologie de l'homme au travail. Le but pratique de l'ergonomie est l'adaptation du poste de travail, des outils, des machines, des horaires et du milieu ambiant aux exigences de l'homme. La réalisation de ces buts au niveau industriel donne lieu à une facilitation du travail et à une augmentation du rendement du travail humain" (1968).

Le terme ergonomie comporte deux racines. L'une indiscutable sur le travail, « ergos », l'autre « nomos » prêtant à discussion dès sa première proposition (loi ou norme selon l'origine grecque ou latine? Lequel prendre d'autant qu'il y a souvent confusion? Lois dans le sens large? Qu'est ce qu'une norme?). Canguilhem, dès 1947, en reprenant le cas de la Western Electric (discuté au paragraphe 1-2), indique que « les ouvriers ne tiendraient pour authentiquement normales que les conditions de travail qu'ils auraient d'eux mêmes instituées, en référence à des valeurs propres, et non pas empruntées ». En d'autres termes, le milieu de travail qu'ils tiendraient pour normal serait celui qu'ils se seraient fait eux-mêmes, à eux-mêmes, pour eux-mêmes.

Sous l'effet de l'évolution des connaissances et des techniques, l'ergonomie est passée progressivement et chronologiquement de l'étude de l'agressivité du milieu extérieur pour l'homme, aux performances physiques et physiologiques et mentales de l'individu sous l'influence des physiologistes et des psychologues. Ces dernières années l'évolution du travail en petits groupes proches physiquement ou éloignés, nécessite une approche plus cognitive et sociologique de la cognition partagée en reprenant et en complétant les approches d'anthropologie sur la communication (Bateson in Marc et Picard).

1-2 Organisation du travail

L'organisation du travail est souvent aujourd'hui abordée dans un sens très générique par le terme management. Le management recouvre l'ensemble des pratiques touchant à l'organisation de la production, la gestion des ressources humaines. Apparu au début du siècle avec l'émergence des grandes organisations industrielles ou bureaucratiques, les premières tentatives de formalisation sont dues à des ingénieurs. Il est enseigné maintenant dans les écoles de commerce.

Il faut différencier le plus synthétiquement possible les approches, indiquant les grandes tendances générales et historiques, des théories des organisations sous-jacentes.

1-2-1 Les approches

Rationaliser le travail salarié devient la principale préoccupation des grandes entreprises dès la fin du XIX ième siècle. Rationaliser signifie adapter des moyens à une fin. La fin reste le profit ou l'augmentation de la productivité du travail en diminuant les temps morts non rentables. Les moyens sont représentés par l'organisation du travail en simplifiant les tâches, en les contrôlant et en adaptant les rémunérations aux tâches effectuées.
Cette rationalisation et l'augmentation du machinisme ont des conséquences sur les relations sociales dans les ateliers et dans les entreprises.
Le nom de Taylor est essentiellement associé à une nouvelle organisation du travail. Le taylorisme constitue une légitimisation du rôle des experts (ingénieurs, techniciens..) déterminant une modification de la structure hiérarchique des organisations. Frederick Winslow Taylor, est réellement le premier organisateur du travail. Il publie à partir de son expérience professionnelle, en 1911 "les principes de la direction scientifique des entreprises". Il est le précurseur de l'études des tâches. Tout travail doit subir une analyse préalable qui se fera à travers une analyse minutieuse de l'existant, décomposition la plus poussée possible des gestes. Son erreur est d'avoir imposé une pratique sur le modèle de l'analyse; de la décomposition des tâches on est passé à la tâche décomposée. Cette approche présente une certaine vision de

l'homme: l'ouvrier est décrit comme un homme isolé, jamais situé à l'intérieur d'un groupe.
L'ensemble du travail de Taylor constitue un immense effort de rationalisation du travail et aboutit à une augmentation de la productivité. L'échec du modèle de Taylor réside dans la dévolution de la science du travail à un seul des partenaires. La brutalité avec laquelle les successeurs de Taylor appliqueront ces principes amènera des conflits sociaux et des dysfonctionnements dans les entreprises. Les directions tenteront de réduire les excès du Taylorisme de deux manières (i) à partir de l'humanisme , interrogation sur l'homme, sa nature, ses besoins (ii) puis par l'analyse de l'organisation , véritable interrogation sur l'homme en situation dans l'entreprise.
Par ailleurs, si l'on reprend les critiques de Georges Friedmann (considéré comme le fondateur de la sociologie du travail en France), le taylorisme produit « le travail en miette ». Le taylorisme est aussi considéré comme l'acte fondateur de l'ergonomie ou science des gestes de travail ! !

Henry Ford aux Etats Unis vers 1914 introduit la liaison des différents postes dans le concept de chaîne. L'unité de travail n'est plus l'atelier mais l'ensemble des ateliers voire l'usine.
En 1933 Elton Mayo dirige ses recherches sur la motivation dans les ateliers Hawthorne de la Western Electric (The Human Problems of an Industrial Civilisation). La modification des conditions d'éclairage n'induit pas l'effet escompté puisque même le groupe témoin, travaillant dans les mêmes conditions que précédemment, augmente sa productivité. S'intéresser aux personnes les motive.
Peter Drucker en 1954 publie « The Practice of Management » et met en place des premiers séminaires de « training-group » aux USA. Il introduit la notion de direction par objectifs.
La première conférence internationale sur le contrôle de la qualité a lieu en 1969.
Enfin plus récemment, Hervé Serieyx publie « le big bang des organisations » présentant le retentissement sur le fonctionnement des entreprises des dernières conditions économiques.
Taiichi Ohno développe (1980) un modèle qualifié depuis de "modèle japonais". Dans la firme Toyota est introduit le flux tendu; en partant de l'aval (le client), l'amont est organisé selon la production "juste à temps".

1-2-2 Les théories de l'organisation :

Aujourd'hui disjointes, les théories de l'organisation se sont construites autour de deux grands pôles: l'analyse du fonctionnement de l'organisation et l'étude du comportement des individus. L'exhaustivité n'est pas de mise. Seuls les faits pouvant éclairer notre thématique seront évoqués.

L'analyse du fonctionnement des organisations est une véritable étude sociologique des organisations, de l'identité des travailleurs, de la culture ayant induit des approches utilisant diverses théories.

En sociologie des organisations, Michel Crozier développa un courant d'analyse des organisations basé sur l'analyse stratégique. Trois concepts clés de l'analyse stratégique doivent être rappelés :
(i) le système d'action concret (l'organisation est un construit humain, l'acteur crée le système) (ii) la zone d'incertitude (il faut un certain degré de liberté, une zone d'incertitude que l'homme puisse garder pour lui et réguler personnellement) (iii) le pouvoir (pouvoir hiérarchique, pouvoir basé sur les compétences).
L'entreprise peut être considérée comme une institution. Se posent alors les liens entre entreprise et société. Des liens d'identification et donc de création d'identité individuelles et collectives se développent.
La sociologie de l'identité et de la culture est due à Renaud Saintsaulieu (identité au travail) et l'analyse de l'influence des cultures nationales à Philippe d'Iribarne (systèmes de valeurs différents en fonction des cultures). La manière française de vivre ensemble, reprend toute une série de thèmes « Tocquevillien » (notamment l'opposition entre nobles et roturiers). Cette logique de l'honneur fait qu'un exécutant ne saurait accepter une tâche qu'il juge inférieure à sa compétence et donc à sa dignité. En lui proposant cette tâche, son supérieur le bafoue et le traite de roturier ce qui lui est insupportable. L'honneur commande avant tout de ne pas s'abaisser, de ne pas « s'avilir », de ne pas « se plier ».

Les approches systémiques
La théorie générale des systèmes a été appliquée aux organisations à la suite des travaux des fondateurs comme Ludwig von Bertalanffy. Jacques Mélèse est le créateur de l'analyse modulaire de système et Jean-Louis Le Moigne a modélisé cette théorie au profit des organisations.

En dehors d'approches générales et sociales des groupes et des organisations des approches centrées sur les individus dans l'organisation ont aussi été développées.

Il faut citer l'école des relations humaines, avec l'expérience Hawthorne et l'enquête de la Western Electric, menée par Elton Mayo.
La théorie des besoins et de la motivation est due à Donald Mac Gregor après les travaux de Maslow (au management rationnel et autoritaire est opposé un management participatif). La dynamique des groupes et du leadership ont été

étudiés et développé par Kurt Lewin. Enfin là encore pour essayer d'être le plus exhaustif possible sans se perdre dans les nombreux courants des approches mentionnons les approches psychanalytiques, cognitives (Herbert Simon) et ethnographiques.

2 – Systémique et pensée complexe

2 – 1 La systémique

L'approche systémique n'est elle pas selon Joël de Rosnay la base de la nouvelle culture de "l'honnête homme" du XXI siècle?

"Je tiens pour impossible de connaître les parties sans connaître le tout ainsi que de connaître le tout sans connaître particulièrement chacune des parties". C'est de ce dilemme énoncé par Pascal qu'est apparue l'approche systémique.

L'approche systémique est née vers la fin des années 1940. Elle est le fruit d'une rencontre entre chercheurs venus de plusieurs sciences. Parmi les pères fondateurs, quatre noms émergent: Norbert Wiener, (professeur au MIT de Boston, théoricien de la cybernétique) Warren Mac Culloch (créateur de la bionique) Ludwig von Bertalanffy (biologiste et auteur d'une théorie générale des systèmes) et Jay W Forrester, (électronicien au MIT qui va tenter d'élargir le champ d'application de la cybernétique à l'entreprise industrielle puis au système urbain).

Comment en effet décrire le fonctionnement d'organismes qui sont doués de propriétés comme l'autorégulation de leurs fonctions (homéostasie), la coordination spontanée de multiples éléments indépendants, la poursuite de la finalité. L'ensemble de ces interrogations aboutira à la formulation de la systémique, c'est à dire de la théorie des "systèmes" qui se définissent comme des éléments interdépendants, organisés et autorégulés.
L'approche systémique repose sur trois grands principes fondateurs: (i) interaction ou interdépendance (on ne peut connaître un élément sans connaître le contexte dans lequel il interagit) (ii) la totalité (le tout est supérieur à la somme des parties) (iii) la rétroaction (type de causalité circulaire ou un effet (B) va rétroagir sur la cause (A) qui l'a produit).

A quoi sert une approche systémique? L'analyse analytique et l'analyse systémique sont plus complémentaire qu'opposées. A des fins de clarté mais

nécessairement excessives, le tableau 1 (adapté de Joël de Rosnay) synthétise ces différences.
Les applications de la systémique vont aujourd'hui de la biologie cellulaire aux organisations des sociétés et du travail.

2 – 2 La pensée complexe

Le terme "pensée complexe" (ou le paradigme de la complexité) fait bien sûr référence, mais non exclusivement, aux différents travaux et publications du philosophe français Edgar Morin.
"A une pensée qui isole et sépare, il faut substituer une pensée qui distingue et relie. A une pensée disjonctive, il faut substituer une pensée du complexe, au sens originaire du terme "complexus": "ce qui est relié ensemble".

De fait l'hyperspécialisation empêche de voir le global (qu'elle fragmente en parcelles) ainsi que l'essentiel (qu'elle dissout). Or les problèmes essentiels ne sont jamais parcellaires et les problèmes globaux sont de plus en plus essentiels. Une intelligence incapable d'envisager le contexte et le complexe planétaire rend aveugle et irresponsable.

Boris Cyrulnik, avec une vision d'éthologue, analyse que « l'on trouve côte à côte dans le domaine médical, mais de manière bien séparée diverses spécialités : neurologie, neuropsychologie, psychologie expérimentale… Chacun voit finalement son propre confetti du monde et cela crée des situations complètement absurdes. Vous avez accumulé tous les savoirs sur le confetti, vous êtes le meilleur spécialiste en confetti, résultats : vous en concluez que le monde est analogue aux confettis. Cela est une faute de pensée provoquée par notre organisation universitaire, où l'on morcelle le monde, où l'on fait des laboratoires, des chaires, des revues de plus en plus pointues puis on généralise… Pour prendre une analogie avec le rugby, je crois que la philosophie de « troisième ligne » est nécessaire. Elle permet d'avoir une vision globale du jeu ».

Quels sont alors, résumé en moins d'une page (gageure quasiment impossible pour synthétiser le travail d'une grande partie de la vie d'Edgar Morin), les sept principes de la pensée complexe ?

1 - **Le principe systémique ou organisationnel** qui lie la connaissance des parties à la connaissance du tout selon Pascal. Le tout est plus que la somme des parties mais le tout est également moins que la somme des parties dont certaines qualités peuvent être inhibées par l'organisation de l'ensemble.

2- **Le principe "hologrammatique"** met en évidence cet apparent paradoxe des organisations complexes où non seulement la partie est dans le tout mais où le tout est inscrit dans la partie.

3-Le principe de la boucle rétroactive rompt le principe de la causalité linéaire: la cause agit sur l'effet et l'effet sur la cause.

4- **Le principe de la boucle récursive** dépasse la notion de régulation dans la mesure ou les produits et les effets sont eux-mêmes producteurs et causateurs de ce qui les produit.

5- **Le principe d'autonomie/dépendance** (**auto-éco-organisation**): les êtres vivants sont des êtres auto-organisateurs qui sans cesse s'auto-produisent et dépensent de l'énergie pour entretenir leur autonomie. Comme ils ont besoins de puiser de l'énergie (information, organisation) dans l'environnement, leur autonomie est inséparable de cette dépendance et c'est pourquoi il faut les concevoir comme des êtres auto-éco-organisateurs. Un aspect clé de cette auto-éco-organisation vivante est que celle ci se régénère en permanence à partir de la mort de ses cellules, selon la formule d'Héraclite "vivre de mort, mourir de vie".

6- **Le principe dialogique** unit deux principes ou notions devant s'exclure l'un l'autre mais qui sont indissociables en une même réalité comme dans le principe d'Héraclite.

7- **Le principe de réintroduction** du connaissant dans toute connaissance. Toute connaissance est une reconstruction

3 – Propositions émergeantes pour des applications au travail

Comment à partir des synthèses effectuées sur les différentes théories et approches sur l'organisation du travail et de l'ergonomie, en intégrant la théorie des systèmes et le paradigme de la complexité proposer un autre regard sur le travail de l'homme et sur l'homme au travail?

3 – 1 Quelles sont les évolutions majeures des organisations?

Si nous focalisons notre propos sur les armées françaises, deux grandes sources de modifications du travail et de l’activité des militaires peuvent être isolées : l’explosion technologique et en particulier les Nouvelles Techniques d’Information et de Communication (NTIC) et la professionnalisation.

Pour les NTIC les enjeux se situent au niveau des interfaces mais surtout au niveau de l'impact sur les tâches et activités.

La professionnalisation des Armées françaises se traduit en relation avec des contraintes politiques et financières, par une réduction des effectifs induisant une nouvelle organisation et des nouveaux métiers.

Le tout concourt au changement du travail, à l'organisation sociale différente du groupe, incluant les problèmes de pouvoir et d'espaces de liberté des différents acteurs (Crozier et Friedberg)

3 – 2 Pluri et/ou interdisciplinarité

Nous avons vu précédemment qu'avec Auguste Comte et la démarche positiviste, la science s'est scindée en disciplines distinctes et hiérarchisées. Ce cloisonnement hiérarchique est toujours très vivace car basé sur une démarche très cartésienne. On arrive même à une différence de noblesse entre les sciences dites fondamentales comme les mathématiques, la physique et les sciences pour l'ingénieur qui sont plus des sciences de création. L'ergonomie, puisant ses origines dans des disciplines existant déjà doit effectuer en permance des compromis. Mais ne s'est elle pas progressivement encapsulée en spécialité érigée en science du travail? Elle n'a pas aujourd'hui (même si certains essayent de le faire croire) cette vue générale totalement transversale pour privilégier cette large culture s'intéressant à la totalité de l'homme au travail.

Le monde du travail dans lequel nous évoluons aujourd'hui, est issu de la pensée mécaniste, véritable vision du monde remontant à plusieurs siècles, en particulier à la fin du Moyen Âge, lorsque l'horlogerie et l'imprimerie furent inventés. Cette pensée mécaniste, analytique, engendra des développements sociaux et économiques essentiels. Elle a trouvé réellement son plein épanouissement dans le Taylorisme, avec l'organisation scientifique et rationnelle du travail. La complexité des situations actuelles, l'imprédictibilité des choses, les organisations à mettre en œuvre doivent utiliser de nouvelles références. En effet, la pensée mécaniste analytique si elle est capable de répondre aux situations compliquées, elle est insuffisante pour répondre aux défis de la complexité des choses. Lorsque les organisations pénètrent dans un univers complexe "elles doivent avoir le courage d'adopter un mode de pensée complexe, car on ne peut plus affronter du mou-flou (l'environnement actuel) avec du dur-sûr (organisations traditionnelle)" (Crozier et Serieyx, 1999).

Donc l'esprit français privilégie l'hyperspécialisation. Le mode analytique est encore privilégié par rapport à l'approche systémique. Comme nous l'avons

indiqué précédemment, il nous faut considérer plus couramment le mode systémique et donc développer l'interdisciplinarité.
Mais il faut éviter que l'interdisciplinarité, objectif vers lequel il faut tendre, ne tue les disciplines. En effet la discipline circonscrit assez bien un domaine de compétences. L'interdisciplinarité est un mélange de compétences, encore faut-il que ce mélange existe réellement pour éviter que l'interdisciplinarité ne soit que réalité virtuelle. Une action interdisciplinaire est une action de coopération, de communication et d'échanges entre disciplines. Son évaluation reste un élément capital, mais aujourd'hui les méthodes d'évaluation ne comportent pas encore de critères adhoc.

L'interdisciplinarité pour quelle puisse être mise en évidence et soit efficace nécessite l'existence d'un « architecte », véritable synthétiseur ou intégrateur des travaux menés dans chaque discipline. A titre d'illustration nous pouvons mentionner schématiquement la démarche de prise en compte du facteur humain dans les nouveaux programmes de la Marine Nationale. Une véritable procédure a été écrite (Instruction générale de prise en compte du facteur humain – IGFH), positionnant pour chaque organisme intervenant dans le programme, un responsable facteur humain. Si la formalisation précédente est bien sûr une avancée par rapport au passé, elle n'en constitue pas moins un patchwork correspondant aux associations de spécialistes de disciplines ou de profession différentes. Dans ce cas, au minimum il faut une structure de supervision pour la vision globale de l'ensemble, de manière entre autre à observer et détecter si des trous ou des manques n'existent pas dans ce puzzle, si des pans entiers de domaines n'ont pas été oubliés. C'est l'objectif essentiel du responsable de programme, qui est malheureusement fort souvent seul. De plus, il ne possède peut être pas toujours les connaissances et les compétences nécessaires pour réaliser cette vision d'ensemble.

3-3 Quelques propositions pour une approche interdisciplinaire:

En fonction des éléments évoqués précédemment sur la pluri et interdisciplinarité, quelques propositions pratiques peuvent être développées pour mettre en place ces concepts. La première concerne directement les différents acteurs, c'est à dire les disciplines impliquées dans le développement d'un programme. Comment concrètement au niveau de ces acteurs converger vers une approche interdisciplinaire ? La deuxième proposition est plus structurelle ou organisationnelle. Quels sont les critères organisationnel pour que ces différents acteurs interviennent ?

- La création d'un réseau pluridisciplinaire dédié à une application précise:

Dans un développement de matériel nouveau, les acteurs de disciplines différentes devant intervenir sont multiples et variées (ingénieurs, opérationnels du domaine, ergonome, ergologiste, médecin, psychologue, sociologue…). Ils sont d'origines et de cultures différentes, de formations différentes et l'interdisciplinarité visée n'est pas facile à stimuler et à mettre en place. Par ailleurs même à l'échelle de la France, toutes ces spécialités ne sont pas forcément géographiquement voisines. Alors pourquoi ne pas utiliser les NTIC pour résoudre ce problème d'interdisciplinarité? Il convient de créer des réseaux pluridisciplinaires dédiés à une application spécifique.

Une analogie avec les réseaux neuronaux peut être faite. Les travaux de Hubel et Wiesel, de Jean-Pierre Changeux, en neurosciences de la vision, ont bien illustré ce fonctionnement par réseaux neuronaux plus ou moins complexes et plus ou moins spécialisés. Ainsi pour la vision, le plus bas niveau comporte des cellules reliées entre elles pour percevoir les contrastes et la taille de ce qui est présenté dans le champ de perception. A un niveau hiérarchiquement supérieur, d'autres cellules intégreront des informations d'orientation privilégiées. Puis des informations en provenance de ces groupes cellulaires interpréteront des formes particulières. On trouve alors différents réseaux de neurones spécialisés, depuis les cellules simples (relativement périphériques dans le système visuel) jusqu'aux cellules complexes et hypercomplexes.
Cette métaphore du réseau neuronal peut être appliquée à la résolution de problèmes d'ergonomie en utilisant un paradigme d'ergo-anthropologie. Il ne faut pas oublier de considérer l'homme dans son intégralité.

Le paradigme de complexité stimule le développement d'une véritable « vue de Sirius » sur les différentes disciplines et sur le travail. Il nécessitera d'adjoindre aux consultants experts d'un domaine, des consultants synthétiseurs, capables d'intégrer les connaissances provenant aujourd'hui de voies disjointes voire parallèles issues des sciences économiques, des sciences humaines, des sciences de la vie, des sciences de l'éducation. Cet aboutissement met pleinement en jeu les nouvelles techniques de l'information et de la communication, les réseaux d'experts spécialisés et les simulations de tout type. Le médecin peut dans certains cas tenir cette place de synthétiseur, dans des projets "médicaux" bien sûr (par exemple télémédecine..) mais aussi dans d'autres projets, dans la mesure ou l'individu le consulte non seulement pour des problèmes personnels mais aussi pour des difficultés dans le travail ou dans ses relations sociales. Or le médecin n'est pas toujours le mieux placé, aujourd'hui, pour représenter cette personne, pour des raisons d'éthique mais aussi car un certain nombre de connaissances issues de disciplines différentes peuvent lui manquer. Il ne saurait être qu'un de ces éléments de ce réseau interdisciplinaire

en apportant sa contribution et ses compétences dans le domaine de la santé, de la médecine préventive essentiellement.
Le paradoxe français est peut être de vouloir faire jouer au médecin ergonome du service de santé des armées ce rôle de synthétiseur. La médecine est la culture de base et la sensibilité d'approche de cet ergonome. Cependant il appartient à un corps dont la majorité des acteurs occupent une position de médecine de soins. Il ne faudrait pas que cette ambivalence médecin-ergonome, facile à prendre en charge au sein d'un réseau interdisciplinaire ne se transforme chez certain en schizophrénie, car en l'état actuel la thérapeutique serait rapidement trouvée et mise en place, supprimant par là même la richesse de la particularité française.

- Faire émerger de nouvelles organisations et modes de fonctionnement :

Michel Crozier soutient que "la réflexion sur l'organisation ne peut plus être une réflexion logique, a priori sur la meilleure façon rationnelle, scientifique, d'organiser le travail, d'allouer les ressources et même de hiérarchiser les pouvoirs et de les contrôler". Ce doit être "une réflexion sur la capacité des groupes humains à coopérer dans des systèmes beaucoup plus complexes et sur les meilleurs moyens de développer et d'utiliser cette capacité".
La systémique est ainsi utilisée dans certaines théories de la sociologie des organisations. Elle peut aussi être associée à la pensée complexe. Hervé Serieyx dans "le big bang des organisations" a repris les cinq principes issus des travaux de Prigogine, Morin, Jacquart qui président à l'organisation. La pensée complexe se situe aux antipodes de la pensée scientificorationnelle, qui elle, sépare et exclut. Les principes présentés dans le paragraphe 2-2 peuvent être déclinés au niveau des organisations modernes.

Le principe d'autonomie explique que dans un monde complexe, les organisations doivent, elles aussi, répondre par un surcroît de complexité. Elles doivent générer plus de complexité en leur sein. En devenant moins compliquée mais plus complexe, l'organisation accroît sa souplesse d'adaptation. Les concepts liés à l'auto-organisation correspondent directement à la mise en réseau grâce à laquelle il est possible de travailler à plusieurs sans être séparés par les cloisons des services et les niveaux hiérarchiques et la simplicité (Intranet). Ce sont aussi le fonctionnement transversal, la responsabilisation, la confiance, la transparence. La notion d'autonomie suppose la fin des contrôles tatillons et improductifs.

Art Mac Neil s'oppose à Douglas Mac Gregor car pour lui, rien n'est plus faux que de prétendre que les individus rechignent à travailler. Ils sont prêts à s'investir dans n'importe quelle tâche s'ils peuvent la situer dans un tout homogène qui a du sens. Ainsi lorsque l'on passe dans les situations de travail, de

la civilisation du geste à la civilisation de l'intelligence, le sens est indispensable. En effet, l'intelligence, on la meut dans une direction. Les employés doivent savoir où l'on va et pourquoi l'on y va. La bureaucratie s'installe dès lors que les employés en viennent à ignorer ce pourquoi ils sont là. C'est l'application du principe de cohérence.

Les organisations ne peuvent pas vivre repliées sur elles mêmes. Elles doivent s'ouvrir pour aller s'enrichir au contact de leur environnement.

Pour Edgar Morin, les dialogiques et par conséquent les contradictions, sont nées du constat que la vie marie à la fois l'ordre et le désordre. Pour une organisation il faut toujours composer avec le court et le long terme, la structure centralisée et la décentralisation, la stabilité et le mouvement incessant, les organigrammes verticaux et le fonctionnement transversal… Il faut en permanence gérer les opposés. Dans une structure de travail, les gestionnaires et les innovateurs concourent tous deux à la survie de l'un et de l'autre, et par delà, à celle de l'organisation.

Conclusions

La théorie systémique et surtout la pensée complexe, intégrant cette démarche systémique, permettent d'obtenir une vue plus globalisante des situations de travail par rapport à la plupart des théories analytiques utilisées jusque là. Elle donne une dimension plus humaine à l'analyse du travail en y intégrant d'autres disciplines comme l'ergologie. En ergonomie une mise en perspective ergologique est en effet nécessaire pour réinterroger à partir de ces conditions acceptables de production de travail abordées par l'ergonome, de ce qui est demandé aux hommes et aux femmes en regard de leur vie humaine. Elle n'est toutefois qu'un des chaînons manquant à l'heure actuelle dans une démarche caractérisée d'ergonomique.
De véritables réseaux doivent être crées, supervisés par d'autres réseaux plus restreints de spécialistes ayant une pratique interdisciplinaire, réseaux qui sont les seuls à pouvoir aujourd'hui posséder une vision globalisante des situations diverses de travail. L'objectif serait alors de créer une véritable démarche Ergoanthropologique, la seule à prendre réellement tous les aspects des situations de l'homme au travail. L'utilisation d'un tel paradigme permettrait dans les années à venir à l'ergonomie de s'assumer pleinement, en évitant lui donnant une dimension plus globale de supervision et d'intégration. L'exemple le plus concret sur lequel elle pourrait prendre cette dimension est sans conteste l'étude des petits groupes au travail.

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Tableau 1
Différences entre les approches analytique par disciplines et systémique

Approche analytique	Approche systémique
Isole, se concentre sur les éléments	Relie, se concentre sur les interactions entre les éléments
Considère la nature des interactions	Considère les effets des interactions
S'appuie sur la précision des détails	S'appuie sur la perception globale
La validation des faits se réalise par la preuve expérimentale dans le cadre d'une théorie	La validation des faits se réalise par comparaison du fonctionnement du modèle avec la réalité
Modèles précis et détaillés mais difficilement utilisables dans l'action	Modèles insuffisamment rigoureux pour servir de bases aux connaissances mais utilisables dans la décision et l'action
Conduit à un enseignement par disciplines	Conduit à un enseignement pluridisciplinaire
Connaissance des détails, buts mal définis	Connaissances des buts, détails flous

Emerging Military Capabilities

Air Commodore S. W. Peach
Commandant Air Warfare Centre
Thomson Building
RAF Waddington
Lincoln LN5 9NB, United Kingdom

THE HUMAN ROLE

Despite the enormous impact of technology in our daily lives, in military hardware and software driven solutions, the human interface with technology remains vital. This may be an obvious point, but when one surveys contemporary defence literature with much mention of Unmanned aerial vehicles, datalinks and near real time global surveillance, the human element may appear absent or second to technology. And yet, all technology relies on the 'smartest' processor ever invented – the human brain. Of course technology aids us in our quest for superiority in business, industry or warfare. But, technology cannot and will not replace the human being. Man and man alone will take the decisions which ultimately determine success or victory in warfare – not machines.

Therefore, I view the opportunity to present an operational perspective by an operator at this important conference as important. In this presentation within my overall theme of the vital importance of the man (or woman) in the pursuance of military activity, I will attempt to place my remarks in a strategic context, since I am an airmen to outline the changing face of air warfare and highlight current and emerging defence technologies in order to highlight the human factors thinking and research which may need to be developed to face the, no doubt, unexpected and unpredicted challenges of the new Century.

Strategic Context

The post Cold War era of international relations has been dominated by regional crises in the Middle East and the Balkans, intra-state conflict in collapsed states in Africa and elsewhere and haphazard international response to humanitarian crises. Each crisis which has invoked a military response, has been hall-marked by generic 'indicators' and 'pointers', but the unique dynamics of challenge and response for each operation bring into serious question the ease of transfer of any military lesson from one region to another.

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And yet each fielding of European forces in an intervention role sparks a torrent of informal and not so informal comment from industry, academics, non-government organisations and pressure groups – depending of the point of view (or internal culture) of the group. Thus perspectives of, say, the Gulf War of 1991-97, Operation ALLIED FORCE over Kosovo in 1999 inevitably vary enormously from the point of view of the 'beholder'. Nonetheless, in an attempt to retain a sense of structure certain key trends can be identified.

Key Trends

- NATO and other International Security Organisations have not collapsed but have continued to adapt to new roles and missions.

- NATO doctrine, techniques and procedures have proved adaptable to different groupings of nations in coalition operations.

- In multi-national operations, internal friction between participants can become a key fault line as levels of commitment are defined by national interest in a more overt way than during the Cold War.

- Throughout the post Cold War era, military equipment designed, developed and procured during the Cold War has had to be adapted to many new roles and missions.

- The gap in military capability between the US and other potential coalition partners continues to widen making true military interoperability elusive.

- The challenges to 'people' engaged in military operations continue to grow in depth and complexity, requiring more commitment to education, training and mission preparation.

Of course, many in the audience will not agree or will take issue with my analysis. My rational for proposing this list of 6 key points is structural in the sense that I wish to draw key challenges in human factors thinking from it. Of course time does not permit to examine each in detail. Instead I will focus upon the changing face of air warfare, mindful of the fact that many of my remarks apply equally to maritime and land operations.

The Changing Face of Air Warfare

The role of air power has provoked debate and controversy from its birth to this day. Since the end of the Cold War, European air forces have deployed aircraft, weapon systems, aircrews and support personnel in every conceivable role. From long range attack over the borders of a sovereign nation (Gulf War 1991, Serbia 1999), through interdiction and close air support in the Balkans and the Middle East, many years of aerial and space-based surveillance and reconnaissance, all backed up by air transport and mobility operations. The importance of shared intelligence and interoperable communications for accurate command, control and targeting – nothing new – has been one generic lesson identified. In addition, air forces and air crews have realised the critical enablers of combat support missions such as the suppression of enemy air defences, electronic warfare, air to air refuelling and air transport to provide mobility of all forces or to assist with humanitarian aid missions. So what, you may ask. Ten years of continuous operations have simply confirmed NATO doctrine, tactics, techniques and procedures. Up to a point, because there are human factors and implications which may offer indicators for the future.

Challenges for Commanders

The exercise of command over other human beings has always been one of the most difficult human challenges. In the nineteenth century, Clausewitz suggested that ‘generalship’ required ‘genius’. In the twentieth, different national experiences in a century of total war added a list of personal qualities such as bravery, honesty, integrity, moral courage, determination and so on. All commanders involved in operations over the past 10 years will have their own list. Items for inclusion will, of course, depend on the context of their endeavour but (I suspect) all will agree that in multinational/coalition operations qualities such as co-operation, tact and diplomacy also have an important role to play. Moreover, in recent years the sheer challenge of managing the volume of data available to contemporary commanders has tended to force commanders towards ‘management by consensus’ rather than command and leadership by ‘personal example’. Whilst there is much to manage in modern warfare, command remains a quintessential human activity and, therefore, my final key point in the strategic context section: the need for education, training and personal preparation is vital for potential future commanders and their key staff. This is a subject you may wish to discuss in questions. For now, I would conclude that changing technology is making this age old problem of command harder not easier and it is to that technology that I now turn.

Emerging Defence Technologies

Whilst human perceptions change constantly, the elemental rules of physics continue to constrain our technological response. In the information age, few in this audience could have predicted the amount of telecommunication possibilities for personal inter-communication. We are surrounded by options and choices for our personal lives – mobile telephones, faxes, email, voice mail, video conferencing etc; the defence sector is no different. Any defence journal abounds with defence companies offering bespoke technology to 'solve' military communication dilemmas, guide the latest 'novel' weapon to high degrees of accuracy with varying degrees of autonomy. The point being that it is the combination of these information-based technologies, which combine to deliver military capability where and when needed. But, several questions remain over the human element.

Key Questions for Defence technology

- Is the technology interoperable with likely allies and friends when operating in coalition?

- Will the degree of autonomy be acceptable in operations of choice with higher levels of political constraint and restrictive rules of engagement?

- Does the integration of the latest technologies simply swamp the ability of the human elements in the command and control chain to exploit the volume of data and turn it into knowledge of military relevance?

- Will future opponents allow 'us' to exploit 'our' military technology or simply avoid engagement by pursuing an asymmetric strategy via operational techniques such as camouflage, concealment and deception, information operations designed to undermine public support and low technology terrorist-based tactics and techniques designed to disrupt 'our' operations?

Technology can assist our military solutions to such profound challenges, but it cannot replace the human requirement to observe, orientate, decide and act – an enduring and lasting construct known as the 'OODA Loop' developed by a United States fighter pilot (Lieutenant John Boyd) during the air war over Korea. The danger is that future opponents will exploit the constraints under which 'we' operate and, through a combination of shorter command chains and ruthless disregard for the norms and conventions of international law, the opponent stays inside our OODA loop. Similarly,

my point on the volume of data applies to the growing enthusiasm for unmanned aerial vehicles (UAVs) and uninhabited combat aerial vehicles (UCAVs). Both are utterly dependent on datalinks and tracking systems, which already threaten to swamp defence networks and available satellite or fibre optic bandwidth with demands for data. Nor, can we claim that our growing reliance upon space-based systems for navigation (namely the Global Positioning System (GPS) may not become a key vulnerability. We know that hackers and potential opponents can build jammers in an attempt to jam or disrupt GPS signals in what is known as navigation warfare (NAVWAR). Of course, in Newtonian fashion we can respond with countermeasures and take steps to improve our secure communications and operational security, but the sheer volume of electronic data may become a key vulnerability to make sense of any military campaign. Again, as with the challenges of command, the human response to emerging technology needs to be carefully considered. I will, therefore, in my final section highlight – from a UK perspective – our current thinking in this vital area.

<u>Human Factors Research</u>

I have attempted to offer a vignette into the strategic context and the military challenges of the modern era in pursuit of military operations. What is clear is that human failings, frailty (not least physiology) and our understandable drive to reduce and minimise (not remove) casualties in warfare require a new approach to human factors research.

Turning to the detail (at last some might say) we have tended historically to focus upon procedural research (how to undertake a task) through the semantic (which task to do) to the episodic (why are we doing the task). Thus, in addition to the already considerable list of tasks we place on our commanders, we may add:

- the need to understand the task to be undertaken in either a manned or unmanned solution.

- define the standard for completion.

- develop and refine training, education and preparation standards.

- understand skill fade.

We have been working in conjunction with the UK Defence Research Agency's Centre for Human Sciences on designing Mission Essential task methodology, Course Development for new aircraft

and weapons systems such as Eurofighter and to examine skill fade. I will examine each (briefly) in turn. During the 1997 UK Strategic Defence Review, the UK government defined, in addition to our extant NATO responsibilities, support to regional conflict outside the NATO area is a key military task for UK forces. Within that military task, NATO and UK military doctrine identifies control of the air as a core capability. Within the UK forces, the Air Operations Manual defines how offensive counter air operations might be used to achieve the required degree of control of the air. This task can now be cascaded to a specific aircraft type or weapon system as a mission essential task. For example, a tactical level training requirement could be defined as ‘GR7 Harrier to destroy aircraft on an airfield in a low threat environment using precision guided munitions’. Thus, this methodology can be modelled in terms of ‘what, where, when and with whom’ and by applying operational analysis modelling blended with military judgement to assess the performance required against specific scenarios to a standard set and measured by Operational Performance Indicators. We continue to develop and expand this methodology to all mission essential tasks.

<u>Eurofighter</u>

Turning to Eurofighter as a new and exciting weapon system for us anyway ! In terms of capability we plan to begin training on a desktop system to build initial systems knowledge which is enhanced and developed by cockpit trainers and interactive systems to build spatial awareness and switchology prior to full exploitation of the Full Mission Simulators to build and develop situational awareness. This graduated approach is, in our view, necessary given the level of technology and complexity in the Eurofighter cockpit. For example, although Eurofighter will be relatively easy to fly with carefree handling, the integration of helmet mounted sighting system and hands-on throttle and stick (HOTAS) will require this step by step approach to learn how to ‘operate’ the aircraft as a weapon system. Furthermore, the full mission simulation will be linked on a local and wide area network to allow collective training and full mission rehearsal.

<u>Skill Fade</u>

A third phenomenon we have experienced over the past 10 years is the reality of skill fade as aircrew, commanders and mission support personnel are deployed in multi-role missions under specific operational conditions which inevitably means that other skills fade. Identifying priorities to determine which skills ‘fade’ quickest and what has to be done to minimise the ‘fade’ within resources available and time taken to refresh factored into the equation is difficult. This is because, not least, modelling and simulation cannot replicate the stress and anxiety levels experienced on real

operations. Nonetheless, during and following Operation ALLIED FORCE, scientists from the Air Warfare Centre attempted to develop a database to assess the skill fade associated with Royal Air Force Harrier operations in the precision guided munitions delivery role.

For the purposes of the modelling, the pilots were categorised as ‘pre operation experts’, those ‘qualified’ prior to the operation, those qualified during the operation and those not qualified. Following the operation, each pilot’s missions were listed together with the assessment of the success of the mission. Those in the audience who are more technically and statistically aware than me, may argue over sample sizes and the subjectivity of the assessments. Perhaps unsurprisingly the statistical analysis revealed that there was a correlation between experience and the ability to identify difficult targets. This is more than a glimpse of the obvious; when the ‘man in the loop’ is included at the right place in that loop, even under difficult conditions, through adverse weather or enemy action means that we stay ahead of the opponent.

If that human element is removed, or placed in the wrong part of the loop/equation, the decision making element – when things go wrong – means that the opponent is ahead and can more easily exploit a mistake in targeting by counter intelligence or attacking public support. Thus, our thinking about the place and role of UAVs and UCAVs must take more account of where to place the decision maker and how much influence is granted to the decision maker – wrong place, wrong decision – advantage handed to opponent in asymmetric warfare !

Future Issues

There are many issues which will need to be addressed over the coming years: conceptual, doctrinal, organisational, cultural and physiological. Each will affect the military future in a different way and to varying degrees. For example, too often defence technology has tended to be ahead of the conceptual and doctrinal concepts. Doctrine is then amended to match what is technically achievable. In future, we will need to ensure coherence between concepts, policy, doctrine, tactics and innovation to stay inside the OODA loop of the opponent. But, perhaps above all, it is the cultural issues which will confound us. The technology to exploit UAVs and UCAVs is not beyond the reach of NATO forces. What is difficult, however, is ensuring that the technology fits into the overall cultural context. Air forces remain dominated by pilots; this policy remains correct for the platforms and capabilities in service or those just about to enter service. But, as we enter the era of real capability delivered by UAV and UCAV, we may need to challenge the primacy of the pilot’s club. As the distinguished RAAF academic, Dr Alan Stephens has opined that “prudent air services

will be planning right now what kind of people they will need to command, control and operate new (unmanned) systems, given that the workforce which has traditionally completed the task may be smaller and aircrew may not be suitable" (Taken from The High noon of Air Power, RAF Air Power Review, Vol 2 Number 2, Summer 1999, Page 13). Are we up to that cultural challenge ?

The message to close upon for syndicate discussion is the need for a coherent approach to these issues rather than a fragmented focus from either the academic, technological or military communities. I look forward to our discussion.

Is There a Future for Human Factors in the 21st Century?

Nahum Gershon[1]
The MITRE Corporation
1820 Dolley Madison Blvd.
McLean, VA 22102-3481, USA
Gershon@mitre.org

"…The development of Mosaic/Netscape is a good example of the value of Human Factors. We should use it to convince our high level management that they should invest more funds in this area…"

A distinguished Speaker, 1996

I was quite surprised to hear this declaration at a Human Factors meeting a few years ago. After all, Mosaic was developed by undergraduate students who might never have heard the term "human factors". This made me ponder why did the distinguished speaker not find better **recent** examples developed by the Human Factors community instead of resorting to a development not made by this community? How could such a breakthrough in human computer interaction (and human information interaction- HII) be developed without the help of the Human Factors community? Could the Human Factors community in its present form design and develop such a visionary interface? In the rest of this paper, I would like to dwell on some of the related but crucial questions and challenges facing the Human Factors community.

To my mind, the answer is simple. Measurements and usability testing have been the cornerstone of our profession. The achievement list of Human factors is quite long (in areas including, for example, information displays and other sensory level systems, refining the computer mouse, and the desktop metaphor). However, in the process of doing our work, we have lost some of our vision.

This community attracts talented people who are interested in the important details of practicing this noble trade. To push the envelope further, we need more people who have a broader and fresher (though sometimes uncertain) look—people who can look into the future and come up with new ways of thinking. Measurements can come later.

Not everything can be measured or modeled. Natural decision making is a good example—people make decisions based on not-so-logical considerations. Tacit knowledge is another example. Could everything be expressed precisely with words or equations? How could Human Factors in its present form evaluate interfaces and processes that cannot be mathematically or precisely defined (e.g., storytelling)? We need to form a deeper contact with people for whom we design a system, a contact different from the one formed by asking questions or filling out forms.

[1] The points of view expressed by the author do not reflect the official policies and points of view of the MITRE Corporation.

Human Factors needs to be more humanized (Bice Wilson, private communication). There is no average human being, no one uniform culture, and no one common objective interface. Different people and different cultures might require different genres or even different media. User satisfaction is a prime goal even if at times it is subjective. The Human-Computer Interaction community does not invest enough resources to address these essential issues.

We need to rediscover the power of common sense. Certain things are obvious and do not need to be measured. Certain things cannot be measured easily or not at all, but nevertheless are quite important. Aesthetics, taste, coherence, simplicity, and feeling good do matter (John Seely Brown, private communication). In some situations, models are helpful and in others they could be an impediment. The challenge is how to find the balance between intuition, common sense, good design, and measurements.

We seem at times to have lost our good sense of design. Here is an example: at a meeting on Human Computer Interaction a few years ago, the coffee cups were in one corner of a large exhibit hall and the coffee in another. At the same conference a few years later, the coffee condiments and tea bags were invisibly far away from the coffee and hot water (see figure), yet no one seemed to complain. When I complained, some people didn't

understand why. We need to pull our heads from the sand and do more of what we preach. Design is more than just cockpits and computer interfaces—it encompasses all aspects of life (see, for example, Don Norman's *Design of Everyday Things*).

We need to reconnect with the social context and impact of the systems we help to develop (John Seely Brown, private communication). The way people are accustomed to doing things seems to make them comfortable. When we develop new genres, we develop new "socially constructive interpretive conventions" (Brown and Duguid, 1994) of ways of doing, interacting, and interpreting. This is negotiated between the developers

and the users and it takes some time to develop and mature. Again, the professional Human Factors community does not pay enough attention to these important considerations.

Some Promising Beginnings

There are some promising beginnings, however. These approaches include user experience design and participatory design. In user experience design, the interface includes the total experience of the user (see, for example, *Experience Design*, by Nathan Shedroff). In participatory design, people actively participate in the design of their information systems environment. Here are some examples:

"Think of the computer not as a tool, but as a medium," says Brenda Laurel in her book *Computers as Theater*, where she proposes to use the vast experience we have gained over generations from theater in designing user interface. In Apple Computers' Guides Project, Abbe Don, Brenda Laurel, and Tim Oren used anthropomorphic agents to help people find information. Storytelling is another way to involve people in the design process. Tom Erickson describes the use of storytelling to get information from users about "messy, ill-defined issues that pervade their daily practice."

Final Word

"Je pense, donc je suis" ("I think, therefore I am"), René Descartes, 1637
"Je mesure, donc je suis?" ("I measure, therefore I am?"), 2001

Traditionally, Human Factors has been only a part of the process of development. To enhance the perception of upper management about the necessity and importance of the field, it has to rise above the details, be more visible, broaden its perspective, and incorporate design and system evolution development in a more proactive way. Human Factors desperately needs to recruit designers and artists into its crowd, and it needs to capture the heart of the people.

These are not easy challenges, and they require more than a quick fix. However, the steps I have outlined are necessary for improving the health and strengthening the future and the potential of this important field. Overcoming these challenges will enable Human Factors to develop future systems equivalent to the mouse and the Web browser.

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Simulation d'exploitation opérationnelle et conception des organisations futures

Dr. Alain Bry
Chef de la section Facteurs Humains
De l'état-major de la marine
(antenne « Programmes »)
BP 55
83800 TOULON NAVAL
France

L'être humain tient sa spécificité d'individu réputé supérieur à sa faculté de pouvoir utiliser un système de codage hautement élaboré qu'est le langage.

Le langage permet de nommer les perceptions, de générer des idées, de bâtir de la connaissance, d'interpréter à l'infini selon des modes spécifiques, bref, de créer des cultures dont les frontières sont en mouvement permanent (1).

Le langage est indissociable de l'intelligence, au sens où il apparaît comme son moyen privilégié et incontournable d'expression. Même l'œuvre d'art, expression le plus souvent iconique de l'intelligence, est, depuis Kant, un sujet de réflexion comme un autre. Elle ne renvoie pas à une mystérieuse transcendance pré-établie mais à l'intersubjectivité humaine ouverte à l'imagination, au devenir, à la liberté de l'intuition.
Cette orientation s'est enrichie par la suite des perspectives historiques (Hegel) de la création humaine et relativiste de la notion de sujet, de conscience et de rationalité du *cogito*(Nietsche).

Cet historique trop sommaire et simplificateur n'a pas d'autre objectif que de situer aujourd'hui les constituants fondamentaux de tout processus de simulation, à savoir :

- la formalisation par le langage des idées, et la formalisation par l'image dynamique et reliée à l'idée des représentations d'une réalité quelle qu'elle soit ;
- l'abord cognitif et psycho-physiologique enrichit tous les jours ces « intuitions » philosophiques en suggérant des modèles et des hypothèses d'organisation et de fonctionnement de la boîte noire que constitue encore le cerveau humain d'aujourd'hui (2).

On sait bien que le cerveau gauche, présumé de la rationalité, est le siège des aires du langage comme on appréhende le fait que le cerveau droit « traite » plus volontiers les émotions et les synthèses (3).

Le temps mis par les philosophes à « unifier » des notions traitées par des aires cérébrales distinctes ne peut manquer d'interpeller dans une vision systémique et épistémologique de l'histoire de la pensée.

« L'art de la guerre est un art tout d'exécution » disait Napoléon. On ne peut soupçonner le stratège reconnu de n'avoir voulu indiquer par là qu'une présomption d'activité ordonnée selon des normes intangibles.
Au contraire, la faculté de manœuvrer rapidement et harmonieusement ne peut dépendre que d'une préparation minutieuse éclairée par des intuitions brillantes passées au crible d'une critique constructive.

Communication présentée lors de la réunion des spécialistes RTO HFM sur «Les facteurs humains au 21^{e} siècle», organisé à Paris, en France, du 11 au 13 juin 2001, et éditée dans RTO-MP-077.

Finalement, l'idée de manœuvre finale est dépendante d'une bonne perception de la situation réelle future probable (forces en présence), d'une réponse adéquate aux contraintes internes (possibilités de ses forces) et externes (possibilités des forces adverses), et d'une représentation dynamique et contextuelle du futur déroulement probable des opérations sur la base de présupposés assurés ou vérifiés.

Toutes les productions cinématographiques mettant en scène des batailles depuis les temps les plus anciens, représentent les décideurs réfléchissant à l'aide de cartes sur lesquelles figurent des icones symboliques des éléments constitutifs des forces en présence. Le chef de guerre ou décideur militaire anticipe sur un schéma du théâtre d'opérations, ce que sera le combat futur. Il utilise la simulation (basée sur les mécanismes de la ressemblance, d'analogie et d'inférence) pour déterminer la meilleure organisation de son dispositif dans l'espace et dans le temps. Une fois l'idée de manœuvre arrêtée, l'exécution doit être conforme, autre étape particulièrement délicate qu'avait bien notée Napoléon.

Les conditions de la décision dans les opérations modernes reposent sur les mêmes soucis d'anticipation, mais ceux-ci sont très sensiblement modifiés par les moyens actuels et futurs capables de fournir une information de plus en plus précise mais aussi de plus en plus abondante sur toutes les données du théâtre d'opérations. Si la gestion de l'organisation d'un dispositif global demeure vitale pour l'action ; son efficacité finale est largement conditionnée en amont, par la pertinence des dispositifs organisationnels internes des unités au regard du traitement validé de l'information et de la mise en œuvre fiabilisée des moyens d'action. A cet égard, l'exemple du bâtiment de combat constitue un cas illustrant de manière privilégiée cette problématique.

Le central opérations d'un bâtiment de combat moderne est composé d'un groupe d'opérateurs interagissant avec l'environnement grâce à un ensemble de senseurs et d'armes par l'intermédiaire d'interfaces d'exploitation. Les capacités modernes des senseurs peuvent amener le collectif à devoir prendre en compte des centaines, voire des milliers de « pistes » qu'il convient de qualifier tactiquement dans le but d'une mise en œuvre éventuelle des moyens d'action.

La conception de ce système socio-technique complexe est, bien sûr, déterminante pour garantir un fonctionnement optimisé du bâtiment, ce dernier, faisant lui-même partie d'un dispositif intégré en échangeant en permanence un flux énorme d'informations.

La première « ligne de combat » est alors la maîtrise du flux d'informations par le et les collectifs pour permettre la bonne décision au bon moment.
Cette ligne de combat constitue en fait un problème d'ingéniérie intégrée où l'expertise « facteurs humains » doit jouer son rôle pour pouvoir dégager les solutions d'organisation, de présentation d'information, de formation et d'entraînement adaptés au problème posé.

Le raisonnement vaut de la même manière pour d'autres locaux de commandement sensibles comme la passerelle ou le PC plate-forme gérant la mobilité et la sécurité du bâtiment. Il doit même s'étendre à un abord global pour répondre à la question plus large et déterminante : « quel équipage ? – quel plan d'armement pour ce bateau ? ». L'évolution des technologies exige une authentique synergie entre le système technique et les hommes qui le conduisent et le rendent disponible.

Cette synergie est impossible à bâtir sur la base de la simple ressource langagière fût-elle instrumentée par des méthodes d'analyse nombreuses et complexes. Le recours à la représentation future du système par le moyen de simulateurs d'étude est indispensable car gage de succès et d'économies substantielles. En effet, les contextes opérationnels infiniment variés et les savoir-faire développés par les opérationnels pour s'y adapter, sont inconnus pour leur grande part de l'industrie car il s'agit d'un domaine de connaissance très spécifique, peu partagé et en essor permanent avec l'évolution des menaces, des doctrines d'engagement etc…

Pour définir ces systèmes, le concepteur ne peut se passer d'une participation active et raisonnée des utilisateurs finaux, très en amont dans le processus. Le but est de déterminer les automatisations nécessaires, le partage optimisé des fonctions entre l'homme et la machine mais aussi l'organisation humaine adéquate qui ne peut être considérée comme donnée d'avance par l'expérience acquise sur les systèmes précédents.

C'est une remise en cause globale qui est nécessaire et qui ne peut être abordée que par l'empirisme utilisant un référentiel commun indiscutable susceptible de faire converger rapidement vers les solutions appropriées. Aujourd'hui, l'industrie considère que l'activité de conception des systèmes d'exploitation en général est très risquée et le traduit par des provisions importantes dans ses coûts.

Si l'on veut réduire les coûts, tout en se garantissant des conditions d'exploitation optimisées, bref, si l'on veut gagner la « première ligne de combat », il convient d'utiliser largement dans les études en amont tous les outils de simulation ad hoc dont le prix est aujourd'hui devenu « marginal » par rapport aux enjeux. Les simulateurs, autrement nommés illustrateurs de besoin d'exploitation opérationnelle permettent d'implémenter rapidement des solutions d'organisation socio-technique, alternatives à des fins d'expérimentation par des collectifs dûment formés.

Les itérations prenant en compte les modifications jugées nécessaires sont alors à même de faire émerger le concept d'exploitation adapté aux différents scénarios, y compris les plus dimensionnants. Ces concepts d'exploitation exigent globalement aujourd'hui une grande flexibilité. Les qualités et les limites de cette flexibilité doivent pouvoir être spécifiées concrètement à l'industrie pour éviter les interprétations et les malentendus qui sont inévitables si le seul moyen de la parole et de l'écrit est utilisé. Les mêmes avantages sont attendus des représentations dynamiques en 3 D qui permettent de valider les conditions d'habitabilité en général mais aussi de maintenabilité, d'accessibilité, de prévention des accidents, etc… La spécification par l'écrit, la réflexion et la simulation dynamique réintroduisent ensemble une perception globale du monde par le concepteur comme par l'exploitant.

Elle aide chaque acteur à mieux jouer son rôle attendu en partageant simplement la plus grande partie des éléments du problème posé. Finalement, cette utilisation maîtrisée de ces outils permet de redonner un rôle central à l'homme dans le système, celui-ci n'étant plus un servant d'équipement mais un exploitant de moyens divers lui permettant d'exercer au mieux ses talents…

Ce dernier point constitue un résultat majeur car, dans le contexte social ambiant, l'attractivité du métier de marin militaire doit prendre en compte de nombreuses données : désir d'épanouissement, importance de l'individu, besoin de confort, intérêt et qualité des conditions de travail. Même si le métier militaire gardera des spécificités fortes qui sont liées à sa finalité, à savoir, défense de la collectivité jusqu'au bout ; il est évident que le gestionnaire de la ressource humaine, qu'est aussi le marin, doit intégrer ces aspects dans sa politique de recrutement pour disposer des équipages dont la marine aura besoin demain, en quantité et en qualité.

Enfin, la simulation d'étude d'exploitation opérationnelle ne prend son sens que grâce à l'implication des marins. Ce faisant, ceux-ci deviennent acteurs du changement qui se prépare. Cette implication est à terme synonyme de responsabilisation et de motivation accrue. Tous les travaux de la psycho-sociologie convergent pour mettre en évidence l'importance de ce point pour constituer des institutions solidaires et efficaces.

En réconciliant l'homme et ses outils, en générant les conditions d'une solidarité accrue de tous les acteurs, quelque soit leur grade, la simulation d'exploitation opérationnelle représente un moyen « à tiroirs multiples » dont tous les avantages n'ont pas encore été mis au jour.

Elle constitue, en tous cas, un outil privilégié pour préparer l'avenir activement dans un « bien-être que procure le bien-faire » (proverbe chinois).

(1) Kant et l'ornithorynque (Umberto Eco)
(2) Le sens du beau (Luc Ferry)
(3) Atlas du cerveau

Task Analysis, Training and Simulation for Operations Other Than War

Dr. Alexander von Baeyer
Industrieanlagen-Betriebsgesellschaft
Postfach 1212
D-85503 Ottobrunn
Germany

Summary

This paper deals with selected problems of task analysis, training and simulation of Operations Other Than War. After a short introduction into the needs for task analysis of OOTW, special problems related to Human Factors research are addressed. New research issues are the principal goal of this paper.

What is explained is that the main problems lie in the critical task conditions and task elements, rather than in the technical skills. Training and simulation are analysed as far as they aim at behavioural change. A research strategy is put forward, which emphasises the need for research into the ethical and cognitive conditions of OOTW tasks.

Introduction: How does combat differ from Operations Other Than War?

The starting point of this paper is, that combat behaviour differs from behaviour in OOTW. In fact there are new important demands *added* to the traditional military job. In addition, a soldier might even have to fulfil both types of demands, battlefield *and* OOTW tasks. However, some soldiers might be more successful in one or the other area. And this again points directly to the problem of human factors[1].

Unfortunately, a systematic *and* scientific approach towards the demands of OOTW and their determinants has not yet been undertaken. Although many task analyses of OOTW have been performed, they lack definitely a human factors related scientific goal and structure. They are task *lists*, rather than analyses.

Let us have a quick look at those tasks, and how they are so far broken down into knowledge and skills.

- The new OOT tasks mainly require *new knowledge*, especially political, social, ethnical and psychological knowledge. Some of this knowledge is also required in combat tasks.
- The new OOTW tasks also require *new and other types of procedures* and skills, mainly mental skills, e. g. restriction in the use of force, negotiation, bargaining, discussion and decision making on non-military matters; flexible responses to surprising, never rehearsed developments, self control and monitoring.

However, it is not my intention today to enter into a discussion of the task inventories, which do already exist. The scope of my paper is different.

Scope of this paper

The scope of this paper is to present Human Factors *research perspectives*... Therefore, this paper deals with *meta-analysis* and re-evaluates the actual knowledge, *points to essential, but neglected scientific problems* and gives advice on establishing a research and development plan.

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[1] The author of this paper thanks Professor Rainer Kluwe, Hamburg, for his advice and critical comments, when this paper was stil in *statu nascendi*.

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The approach of this paper is structural and synthetic. I want to provoke a discussion on some important hypotheses.

This paper is further divided into four sections:

- A re-evaluation of Task Analysis
- Training for the change of the paradigm
- Simulation of personnel characteristics
- Research strategy and conclusions.

A Re-evaluation of Task Analysis

As every body knows, there is only a soft borderline between OOTW and conventional war actions. But this borderline has a strong impact on the required human behaviour. The difference is threefold:

1. On all operational and tactical levels OOTW serve much more directly political and socio-economic purposes[2]; there are no enemies but only "partners".
2. The goal of any OOTW is to preserve resources, even if destructive means must be applied.
3. Sometimes a OOTW can suddenly turn into a "conventional" military combat operation, and is then guided by the "old" task logic of friends and foes.

OOTW tasks are composed of

- non-combat military tasks,
- tasks widely discussed in the early and mid 1990s about UN peace keeping endeavours
- and tasks derived from humanitarian or other organisations, if the military "interferes" in their business.

All these distinct sources of tasks certainly need systematic restructuring and re-evaluation. But, this would be too much for today.

Instead, I believe that the scientific human factors problems, which really matter, are to be found not in the content of the tasks (in the "operations"), but in the "critical task conditions" and in the "critical task elements"[3].

There are four clusters of critical conditions and elements:

1. The political and media interest – very often unclear and conflicting with operational needs.
2. The ethical conditions – very often creating normative dilemmas and moral risks – and not even an object of military concern.
3. The high mental workload resulting from the political and ethical elements and requiring, in addition to the normal task load, a high degree of self control and self awareness.
4. Communication problems, especially language and other communicative codes – which is due to insufficient combined training.

Let me elaborate on three of these topics a little more, until the *research challenge* becomes visible. And let me begin with a definitorial issue.

1. From the standpoint of human behaviour the term "Operations Other Than War" is not well suited. "War" is primarily a term in international law. I propose therefore to speak here more precisely about *operations with* direct *protective aims*, which in fact may occur also in war, but are the core business of any crisis response and humanitarian operation[4]. Protective aims may however include limited destructive actions as

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[2] Cf. D. Davies, GMU – School of Public Policy, Program on Peace Keeping Policy: in several papers.

[3] I refer to the simple but workable logic of task analysis, which comprises five elements: Input into the task, operation in the task, critical conditions of the task operation, critical task elements and output of the task. Cf. e. g. EUCLID projects, where this task analysis method has been used: RTP11.1 and 11.8, where human factors issues have been applied to simulation.

[4] "Miles protector", a term coined by the Swiss general G. Däniker 1992.

means to an humanitarian end. This implies the ethical task-difficulties, which are all to well experienced but still insufficiently researched within the military context.

2. Lessons learnt from conventional war actions tell us, that the decisive military success (the “kills”) can be attributed to only a few soldiers in every unit and therefore to some mysterious “human factors”, loosely called “Morale, Cohesion, Confidence, Effectiveness”[5]. What is the problem in conventional military action is even more a problem in OOTW. Task Analysis of OOTW must focus also on those human factors, which account for the mission success; whereas the mere technical skills involved can be taken from existing task analyses as they are (or should be).

3. Information “warfare” and dealing with the media is my next point. This issue has a strong impact on soldier behaviour, because he / she may do his / her job under the eyes of the world. There are two basic constraints: First, there must be a *mutual understanding* of the respective “mission” of both the military and the media, and this is an important task element of OOTW. Freedom of information on the one hand, operational necessities on the other hand, have to make compromises. Second, these compromises must serve as a *good example of democratic culture* to the conflicting parties, who are sometimes not good examples of democratic culture. Therefore, a special *dealing with the media task analysis* should be undertaken. The main task difficulty lies certainly in the ability of the soldier to assess in advance the impact of his doing or his information on the public opinion and the public opinion’s impact on the mission success.

4. Operations with protective aims very often place the individual soldier or the unit in a dilemma, whether to comply with the Rules of Engagement (RoE) and to miss the *immediate* protective goal *(hic et nunc)* or to follow a moral impetus and to violate the RoE. Therefore, the *ethical implications* of any protective operation must be of primary concern in the task analysis. And there is still another must: The political and higher command authorities have to be instructed by operational experts, to avoid ethical risks for the soldiers. The basis of all this will then be an *ethical task analysis*, which has to be part of the overall OOTW task analysis. It should deal with the protective attitudes of soldiers and the moral standards of good operational practice – governed by ethical principles and explained on a case by case basis.

   However, the ability to perceive a situation as an ethical problem is not equally developed by everybody and everywhere. Some may see a moral dilemma, where others perceive only business as usual. This fact leads directly to the training of ethical perception. It would appear , situations where simple *reproductive skills* are sufficient, lend themselves quite easily to ethical perception training (using “if ...then ... rules”). Situations where complex *productive skills* are needed, require instead the ability to use ethical rule based reasoning. And it is here, where the difficulties really begin. – Who gives the rules and how authoritative are they ?

5. *Cognitive task analysis* plays a central role in task analyses for OOTW. Main task requirements are related to cultural and political understanding, as well as concerning self control or *self monitoring*. The latter is particularly important on all operational levels, because even simple actions of ordinary soldiers can influence the political and social outcome of the mission. However, to determine the need of self control and consciousness in relation to task operation is certainly a non trivial endeavour and requires much psychological competence.

The analyses of political, ethical and cognitive task-conditions and elements require a new research approach. This should be a synthetic endeavour of several sciences. Task analysis for OOTW should be based on the *relevant human sciences*, and can not be confined by military common sense. The sciences involved are: ethics and political sciences, sociology including media impact research, social psychology, and individual psychology. They should produce the conceptual reference system. Indeed, there is still a big knowledge gap and much confusion about the terminology to be used. A military *applicable and scientifically acceptable conceptual reference framework* of the human sciences involved in OOTW is therefore a necessity, even if it will be hard to achieve[6]

[5] Communication by the Institute for Defense Analyses (USA). The examples are air-to-air combat, but also surveys conducted on historical data and after the Gulf War.

[6] Cf. DRG Panel 8 RSG 19 “Cognitive Task Analysis”, which had to struggle with the same problem.

Let us assume that the human sciences can be successful. How could and should these sciences help finally the soldier in the field ? To these simple questions there are three global answers, as far as I can see:

1. A careful evaluation of the task complexity in OOTW will raise the question, whether the so far used personnel selection criteria are really suited for both paradigms, the combat and the “other” paradigm. This may finally help to put the right person in the right place.
2. Any thoroughly done task analysis leads to better training. This is a universal and oftentimes neglected truism.
3. Finally, consideration should be given to the establishment of a NATO/PfP-Standard Task Inventory of OOTW with primary focus on the critical conditions and elements. This would greatly help the soldiers in the field, because most of the OOTW are combined operations.

Training for the Change of the Paradigm

If the meta task analysis, elaborated here, is correct, at least the trend involved , then the main new training challenge is cognitive and ethical behaviour training – not withstanding the tedious but mostly well established endeavours to convey all required technical skills.

From the standpoint of *training research*, behaviour training requires three curricular steps:

1. Establishment of behavioural models including the political, ethical and mental issues – and by models I mean real life examples, based on historical data and field surveys and analysed according to scientific standards.
2. Development of training strategies to acquire the necessary behaviour, especially to reach the high standard of self control and consciousness as well as high communicative skills.
3. Development of methods for documentation, feedback and accreditation of a viable behaviour – in compliance with the state of the art of empirical psychology.

I must leave it to the judgement of the training authorities, whether one or all three curricular steps have been correctly undertaken or advice has been asked to undertake them. However, I would like to cite some crucial *quality features* of training for the behavioural change and I would recommend using them:

The most important and general quality recommendation is *enough time*. Behavioural change cannot occur overnight, unless it is traumatic – and that is not what we want nor can we be sure of its outcome. The answer to the question, what would be enough time, should be given by scientifically evaluated training trials , which in turn should include a well designed curriculum and valid research documentation.

The criteria of a well designed curriculum for behavioural change, including the feedback mechanisms, which lead to the acquisition of a viable behaviour in OOTW, can be defined as follows:

a) A well researched and documented inventory of cases, where required behaviour is decisive for the mission success.

But in addition to this also interpersonal and instructional qualities, such as:

b) quality[7] of the instructor-soldier relationship, i. e. mutual respect of each other’s role
c) high instructor competence in terms of technical and educational skills
d) willingness and co-operation of the *soldier* to work on his/her attitudes towards OOTW (i. e. high feeling of being obliged to the cause of the mission and one’s own responsibility)
e) and once again duration of the training.

As we have already seen in task analysis, the training outcome depends also on personnel characteristics. And this leads us back to the selection problem. Whether the high requirements of combat *and* of OOTW can be

[7] For the following criteria cf. Orlinsky et al., 1994, Process and outcome in psychotherapy – noch einmal. Contribution to: Bergin and Garfield, Handbook of Psychotherapy and Behavior Change, New York 1994. Cited in Kopta et al, Individual psychotherapy outcome and process research, Annual Review of Psychology, 50, 1999, pg. 447. – Using some very general findings of clinical psychology means that the *basics* of behaviour change are comparable.

realised in one and the same personality of a *standard soldier* (which I personally do not believe), can only be ascertained in field surveys under scientific control.

Simulation of Personnel Characteristics

Under the heading of Human Behaviour Representation (HBR) the Operational Research and Simulation community has discovered the human being as a object of modelling and simulation. There is plenty research and development under way[8], most of this aims at adding some human factors to already established simulation models. However, it is recognised that the foundation of HBR in task analysis and psychological basic research would be desirable endeavours.

Apart from modelling anthropometrics and workload conditions, the importance of HBR in OOTW could be threefold:

1. To model the *individual decision making* process on the operational level under the task conditions, I have already described.
2. To offer objective and standardised selection and training opportunities, when behavioural change becomes an operational necessity.
3. And to serve as an analysis tool prior to political and military decisions – remember e. g. the moral obligation of higher authorities to avoid ethical risks.

For the time being, *only* modelling the operational decision making process under OOTW conditions seems to become a successful task. Let me explain this in some more detail.

The *aim* is, to represent the inter-individual differences, which account for different decisions of different people in the same situation – and this as a deterministic simulation. The *approach* is to model those personal characteristics, which can also be found as stimuli of the task and its environment. These are

- cognitive and motivational factors of human action, i. e. action schemata and individual motives that are triggered by situational cues[9]
- and a small number of specific behaviour moderators, which really matter in military scenarios (e. g. stress) but also and
- in particular the political and ethical task conditions of OOTW, elaborated here.

The scientific challenge is, to combine those “human factors” into one “molar” model (with medium “granularity”), which is scientifically true *and* usable in simulation. It is however not the intention and can not even reasonably be argued, to create a psychological all embracing “man model”, a full human agent in war games. What can be achieved is only the modelling and hence the simulation of decision making processes in typified situations (“scripts”).

Organisational behaviour of teams, small and large groups should also be made the object of HBR simulation[10]. This is certainly a great challenge, but for today it is too big a topic.

Research Strategy and Conclusions

Human Factors’ development in the 21st century: I don’t dare give any prognosis. But I know of several research desiderata, left over at the end of 20th century.

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[8] Lately: NATO RTO LTSS on “Human Behaviour Representation” (LTSS SAS 017), 1998-2000. US National Research Council study on “Modelling Human and Organisational Behavior”, 1999.

[9] Cf. the ATS system by D. A. Norman. This is also the starting point and approach of HBR modelling used by the author of this paper and his HBR study team in a project commissioned by the German MoD.

[10] So one of the recommendations by the LTSS on HBR.

As for my topic today I see three main research strands leading to an optimisation of human resources in OOTW:

1. Studies of the match between OOTW task conditions and personnel selection criteria.
2. Empirical research on special behaviour training, aiming at better training strategies and optimal training time.
3. Development of simulation models based on the human factors research, first for individual behaviour, then perhaps for organisations.

To put this research strategy into action, I recommend some priorities:

- First and highest priority, explain to operational people and to training establishments, what HF knowledge and expertise is already available, discuss research issues with them, obtain information about practical research needs. I guess that the training and simulation issues have high priorities. If this is so, task analysis issues (as described above) will automatically follow.
- Approach the ethical questions of human behaviour in OOTW. Even if this may not yield direct practical results, it has a central legitimisation function and will therefore sooner or later be raised. The Human Factors community should volunteer for this issue, because by training and experience it may show the necessary *sensibility*.
- Organise interdisciplinary research on a workable human behaviour model for OOTW / PSO which can be used in training, analysis, decision support and selection. – This is certainly a long term goal, but it should be approached, even if it will become an iterative process with many feedback-loops to the *operational* experience.

Direct Retinal Imaging and Virtual Displays

Dr R J M Jones
Protection and Performance Department
Centre for Human Sciences
Defence Evaluation and Research Agency
Farnborough, Hants GU14 0LX
United Kingdom
e-mail RJMJONES@DERA.GOV.UK

1. SUMMARY

Conventionally, displays employ a display surface to present the visual information, which is then either viewed directly (eg television) or projected into the eye using an optical system (eg head mounted displays). This approach is appropriate when many observers have to see the display concurrently, and can be made to work successfully when applied to personal display applications, such as head mounted displays. Direct retinal imaging (DRI) uses a different approach, in that the visual information is presented directly onto the retina of the user of the display - there is no other display surface where the information is presented. This is usually achieved by scanning a modulated laser beam across the retina to build up the image.

Direct retinal imaging offers potential advantages compared with conventional displays. Perhaps most important is the potential for lower power consumption for a given image brightness. The monochromatic nature of the lasers commonly used as the light sources in DRI systems means that a colour DRI display could easily be engineered to offer a larger colour gamut than that found with conventional display technologies. As the display technology is based on that of the scanning laser ophthalmoscope, it is possible that a DRI system could provide a feedback image of the retina of the user, with little extra cost - this could be used for positive identification of the user of the display, and for point-of-gaze tracking. If the display is engineered with a small exit pupil, most photons would enter the eye of the user, rather than be reflected and scattered from the iris and sclera, and the surrounding skin. This should result in a potentially more secure personal display, with lower signature to image intensification systems.

Some practical optical engineering considerations must be addressed when designing DRI systems. These include the exit pupil size and whether to use pupil tracking, the light source(s) and how to provide the source modulation. It should be borne in mind that DRI technology is still in its infancy, and conventional display engineering guidelines may not be directly applicable.

Some novel human-factors considerations must also be addressed in designing a DRI system. These include zero persistence, the scanning regime, the effect of using monochromatic sources, and the effect of any exit-pupil - eye-pupil tracking on visual performance.

Keywords: Direct retinal imaging (DRI), Scanning laser display (SLD), Virtual retinal display (VRD).

2. INTRODUCTION

Conventional wisdom dictates that if an artificial image is to be viewed, then it must exist as a real image at some point. This real image can then either be viewed directly, such as on a television screen, or via some projection optics, such as in head mounted displays. In some display systems a real image can exist at several points in the system, for example, projected computer displays, where the image exists on the small display panel in the projector, and also on the projection screen.

Direct retinal imaging (DRI) systems do not use a display surface - rather, the visual information is presented directly onto the retina of the user. Essentially, the only real image in on the retina itself. Currently, all DRI systems scan the image onto the retina using a modulated laser beam scanned in two axes. This may seem to be a complex method of producing an image, particularly given the acceptable performance of current

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displays, however, DRI systems are being developed due their potentially high performance in several key areas: high brightness; low power; small size; large colour gamut; feedback of retinal image; security.

The direct ancestor of the DRI is the Scanning laser ophthalmoscope (SLO), which was developed in the 1980's (1). This uses a scanned laser beam to view the retina for medical diagnostic purposes; where two mirrors steer the laser beam in x and y planes to cover the whole of the retina. The reflection from the retina can be viewed directly to give an image of the retina, or the system can use a photodiode in the return path, for remote viewing of the retina on a monitor. As the laser beam has a small diameter, the SLO can give a bright image without dilation of the pupil, and also can image the retina of individuals with poor optical performance.

When the SLO was developed initially it was identified that it was possible to create an image by using a visible laser and modulating the intensity of the laser as it scanned across the retina. This was not followed up at the time, and it took development by Tom Furness at the University of Washington in the mid 1990's to produce a practical display system - then termed the Virtual Retinal Display (VRD) (2,3). The term VRD has subsequently been copyrighted, and applied to a display system which does not directly write onto the retina. It is preferable, then, to call such displays scanned laser displays (SLD), with direct retinal imaging (DRI).

DRI displays are therefore similar to SLOs, but with several crucial modifications: the laser light must be visible, and modulated appropriately for the image; several laser sources can be used for a colour display, and the sources can be directly or indirectly modulated; the exit pupil of the system must be modified, by enlargement, or by linking the exit pupil position to the position of the pupil of the eye.

3. ADVANTAGES

3.1 Brightness, power consumption, size

Although many display applications are tolerant of a relatively dim image brightness (around 100 cdm^{-2}), some, such as see-through display systems for use in daylight, require a high image brightness (potentially over 5,000 cdm^{-2}). These display luminances can be achieved using some conventional display technologies, but usually at the cost of high power consumption. DRI systems can be intrinsically more photon efficient than conventional displays, as potentially all photons produced by the display are available to the retina of the user for phototransduction. Moreover, the monochromatic laser sources can be more photon efficient than the source-with-filter used in some conventional display technologies, and intrinsically produce the collimated light that in some displays necessitates the use of complex optics, with their associated losses. This means that a DRI display can be made much brighter for a given power consumption than a conventional display type. Alternatively, a DRI can be made more power efficient for a given display luminance, with commensurate savings in the size and weight of the laser sources and power regulation systems, and power supplies/batteries. As the sources used are often monochromatic, a reduction in size and weight can also be readily achieved through the use of holographic optical elements (HOE), rather than using heavy glass or plastic; although conventional displays can be engineered to use HOEs, the broad spectrum of the display makes this a complex task.

3.2 Colour gamut

The range of colours that a display can produce, or its colour gamut, is dictated by the colour primaries of the display. This can be illustrated graphically by plotting the colour primaries in CIE x,y colour space, when the range of colours that are theoretically possible for the display to produce will be defined by the triangle with corners at the three points. Figure 1 plots such a colour triangle for a typical CRT and DRI display. As the DRI system uses monochromatic sources, the apices of the colour triangle exist on the edge of x,y colour space, and the resultant triangle is usually much larger than that found with a conventional display. The example DRI triangle shown assumes the use of commonly available laser sources, and more novel sources could enlarge the triangle considerably. The increased colour gamut of a DRI system can be useful on two counts. Firstly, it enables the rendition of a more realistic world in enhanced and virtual reality systems. Secondly, it enables the accurate rendition of coloured warning lights, particularly signal reds and greens; current display technologies render these signals particularly inaccurately.

It is worth pointing out that a colour display can use more than three colour primaries, the resultant polygon defining the colour range of the system. Thus it may be beneficial to produce a display with four colour primaries, giving an enhanced colour range. This would be very complex to engineer into a conventional display technology, and would likely reduce the resolution and maximum luminance of the display. With a DRI system, it would require the addition of only an extra laser source and modulator to create a tetrachromatic display, with no loss of resolution, and with enhanced luminance.

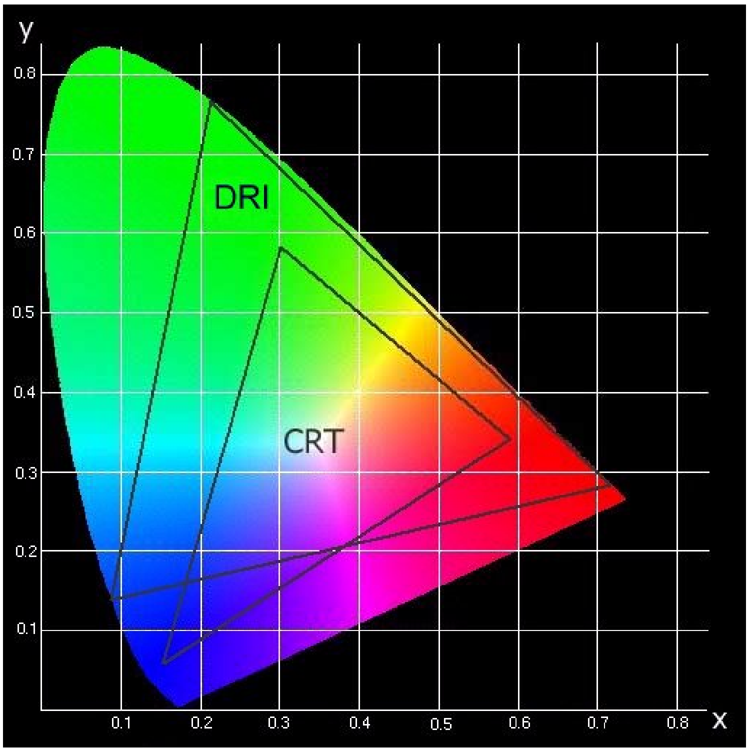

Figure 1. CIE colour space in x,y coordinates, superimposed with a typical CRT and DRI colour ranges. The DRI display uses 633nm (semiconductor), 543nm (HeNe) and 488nm (Argon) primaries.

3.3 Feedback of retinal image

As has been mentioned, current DRI systems use a scanned laser beam to build up the image on the retina. This is similar in operation to a scanning laser ophthalmoscope, but with a modulated source and more complex optics. If a DRI display is engineered to measure the light reflected from the retina of the user then the display would have the ability to produce an image of the retina of the user. This could be achieved with little additional cost over the cost of the display alone. The pattern of blood vessels on the retina is unique to an individual, and changes little through a persons lifetime. Thus the image of the retina could be used for positive identification of the user of the display, and potentially lock-out unauthorised access. Moreover, as the image of the retina moves as the person moves his eyes, this image could also be used for point-of-gaze tracking.

3.4 Security

The DRI display can be engineered such that most of the light produced by the DRI display would enter the pupils of the user, leaving comparatively little back-scattered away from the viewer. This would make a potentially more secure display than is currently available. Moreover, as less light would be reflected away from the user, the display could have a lower signature to image intensification systems.

4. PRACTICAL CONSIDERATIONS

4.1 Safety

Use of lasers in any system opens questions about the safe use of the system, particularly when the lasers are to be viewed directly. The scanned laser DRI concept has been tested against UK, European, US and

international laser safety codes, and has been found that for normal use such displays are at least as safe as conventional displays (4,5). In fact, for some of the safety codes DRI displays had less stringent restrictions than conventional displays, although this is more likely to be due to the sometimes arbitrary nature of the codes, than to any intrinsic extra safety. On failure of either or both of the scanners, DRI displays lie within the limits for safe use set out by the guidelines, at normal viewing luminances. At higher luminances, scanning laser DRI displays could exceed safety guidelines upon the failure of the scanning system, particularly if both scanners fail at the same time (eg, power supply loss) - in the case of higher luminance displays, a safety cut-out would seem to be a prudent addition.

4.2 Exit-pupil size

The exit pupil of an optical system is properly defined as the image of the aperture stop as seen from image space. This definition does not necessarily suit a scanning laser display, and instead the term exit pupil is given to the size of the laser beam at the pupil of the eye. The SLO concept uses a small laser beam, to avoid the need to dilate the pupil, and also to produce a good image in patients with poor optical performance. This is appropriate in the SLO, as the patient fixates on a stationary patch, and as the SLO is solidly aligned to the patient using a chin-rest. DRI displays have an exit pupil less rigidly coupled to the pupil of the eye of the user, as the pupil of the eye moves as the user looks around the scene. Moreover, the display may move in relation to the head, particularly if used in a vibrating, or high-G environment. Thus the DRI must either use a small exit-pupil and track the pupil of the eye, or expand the exit-pupil to cover an acceptable range of eye movements and display mounting shifts.

Small exit pupil:

- The most important problem inherent in a display with a small exit pupil is that the image disappears when not directly viewed, particularly with the small pupil size experienced at high illuminances (figure 2a). One way to avoid this is for the exit pupil to track the eye pupil, however, this itself can bring additional complications.
- The displayed image brightness is independent of eye pupil size - the effect of the loss of the usual link between pupil size and image brightness on the visual system of the user has yet to be fully explored, although preliminary studies suggest that the visual system copes without confusion.
- The small exit pupil also brings with it a large depth of field. This may be advantageous, as in enhanced reality systems it will be likely that display information and real-world information would be in focus at the same time. Also, the image will be in focus for those users who usually require corrective optics, without any adjustment on the display itself. However, the effect of the loss of the usual link between visual accommodation and image focus on the visual system has yet to be fully explored.
- If the exit pupil is tracked, there may be an interaction between pupil movements and saccade. Upon a saccade the exit pupil of the display will need to track the pupil motion at a very high velocity. Although vision is suppressed during the saccade itself, the brain expects to see an image at the end of the saccade, and it is possible that the exit pupil would not reached the eye pupil by this time. The absence of the image at this crucial time may hinder the corrective saccade often necessary for the accuracy of the visual system. It is not known how the visual system will respond to this lack of information.
- It is worth mentioning that with a small exit pupil all of the light energy produced by the display is projected into the pupil of the eye; this gives an energy efficient display, with low signature and greater security.

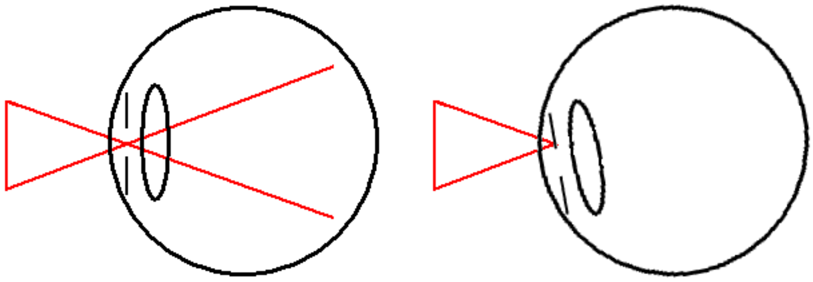

Figure 2a. Small exit pupil system. The schematic on the left shows normal viewing. The schematic on the right shows image loss due to misalignment of the exit pupil and eye pupil.

Large exit pupil:

- While the image doesn't disappear at higher viewing angles, there is the danger of vignetting, that is, of the image brightness varying with viewing angle. This occurs when the exit pupil does not cover all of the pupil of the eye (figure 2b), and will be particularly noticeable with the large eye pupil seen at low light levels.
- There is, however, less need to track the eye pupil.
- Alternatively, if tracking is used, less accurate placing is necessary - a compromise would be a medium sized exit pupil with eye tracking.
- When the exit pupil is large the display behaves more like a conventional display: the brightness of the image varies with eye pupil size; the depth of field is limited; viewers need to use their usual optical correction; signature and security is as for conventional display.

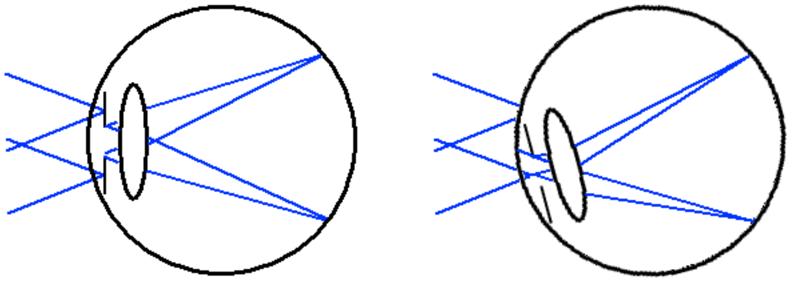

Figure 2b. Large exit pupil system. The figure on the left shows normal viewing. The figure on the right shows vignetting.

The division of the potential DRI system into large and small exit pupil systems is useful for illustrative purposes, however, other approaches exist:

- The system could use many pupils (>50), which would give similar attributes to a large exit pupil system, although system design may be made easier.
- Alternatively, a small number of exit pupils might suffice, particularly if the pupil size is known. This would give all of the advantages of the small pupil system, but might give visual artefacts at points where one exit pupil takes over from another.
- With a small number of exit pupils the exit pupils not being used could be switched off, to give many of the advantages of a tracked single pupil with a lower engineering demand.
- With both types of multiple exit pupil it would be possible to incorporate a variable image quality with viewing angle, which may assist in the optical engineering of the display.

4.3 Light sources

Potentially any light source could be used in a DRI system, however, the complexity of the display is eased considerably by using a small beam of collimated light, and this is best supplied by a laser source.

Semiconductor lasers offer the advantages of small size, low power, high efficiency units that can be directly modulated at high frequency. The disadvantage is that they are only commercially available in red. When green and blue semiconductor lasers become available they will almost certainly be applied to DRI displays. For the time being, a red-only DRI display has advantages of much lower cost over full colour units, and bichromatic displays will offer many of the advantages of full colour displays at a similar cost when green semiconductor lasers become generally available. Blue semiconductor lasers appear to be a distant prospect.

Solid state lasers are available in red, green and blue, and would appear to offer a convenient choice of source for DRI displays. Solid state lasers, however, cannot be directly modulated; the necessary external modulator adds cost and complexity to the system. It is worth noting that a continuous wave (CW) laser is required for the display, and while many solid state lasers appear to be CW, they actually emit a high frequency repetitively pulsed light. Thus they would be difficult to engineer into a DRI display.

Gas lasers also offer red, green and blue light sources, and are suitable sources for DRI displays. Again, they require external modulation, at additional cost and complexity to the system.

Although the display design is eased through the use of a laser source, it might be beneficial to use light emitting diodes (LEDs) as the source. These are point sources and do not emit collimated light, and there are resultant complications in integrating them into the display. However, they are available with outputs at many wavelengths (including red, green and blue), and can be directly modulated, thus they remove what is currently a demanding requirement - the need for external modulation with full colour displays. They can emit a sufficient quantity of light to produce a display with a reasonable luminance, however, the ability of LEDs to produce the very high luminances required by pilots, for example, remains to be seen.

4.4 Modulation

Whilst some sources can be directly modulated, the solid state and gas lasers require external modulation. The only modulation technologies that can give the required high frequency modulation are electro-optic (EO) and acousto-optic (AO) modulation. These techniques are well understood, however, they increase the cost and size of the system.

4.5 Scanning system

Scanning systems broadly divide into reflective and refractive systems.

Reflective systems use a moving mirror to reflect the laser beam in the desired direction. Galvanometer mirror systems move the mirror to a desired position, but have relatively low potential scanning speed. The low speed means that a galvanometer mirror can only be used for a slow-scan. For the fast-scan, two reflective technologies exist. A mirror can be made to vibrate at high frequency, allowing a scanned laser beam (resonant scanner). Alternatively, a polygonal mirror can be rotated at high speed to achieve the same effect.

Refractive systems use a different approach. Electro-optic scanners use materials with a refractive index that varies with electric field. Light bends (refracts) when moving from one refractive index to another at an oblique angle, the angle of refraction depending on the refractive index change. Acousto-optic scanners uses a piezo driver to produce an acoustic standing wave in a medium with a refractive index which changes noticeably over the pressure changes seen in the acoustic wave. This gives a sinusoidal grating of varying refractive index, which diffracts the laser beam.

5. REAL DRI SYSTEMS

DRI display technology is still in its infancy, and to date only a few displays have been created. Laboratory based demonstration systems have been developed by Delft University (6) and by Tom Furness at the HITLab of the University of Washington (2,3). These use polygonal and resonant scanners, respectively. Microvision of Seattle, Washington State, has taken the idea proposed by Tom Furness, and developed it into a full display, which is now commercially available. They have, however, initially produced a CRT replacement solution, which is not a true DRI system, and which offers few of the advantages of a true DRI display. It does, however, offer the advantage of potential high brightness, which is sufficient for many applications.

It should be noted that several companies now offer projection display systems based on scanned laser beams. While it is difficult to engineer a DRI system from a projection display, a DRI display could be engineered to offer a projection display with little or no modification. Thus it may be possible to produce a dual use personal and projection display.

6. NOVEL ASPECTS

6.1 Persistence

Generally, when a display illuminates a pixel, it remains on for much longer than it is directly ‘energised’ - several pixels are illuminated at a given time. In CRT systems this is due to phosphor persistence, which is generally around 50 microseconds; around a line long. In colour TFT LCD systems, this persistence is for as long as each frame. In DRI systems, each pixel is only illuminated for the moment it is energised; only one

pixel is illuminated at a time. This means that each pixel must be very bright, in order to give a time averaged luminance equivalent to that of a conventional display (figure 3).

Because of the limited temporal resolution of the visual system, zero persistence does not affect the visual process of a static image. However, when the image is moved on the retina (perhaps through vibration, or on saccade), artefacts may be seen.

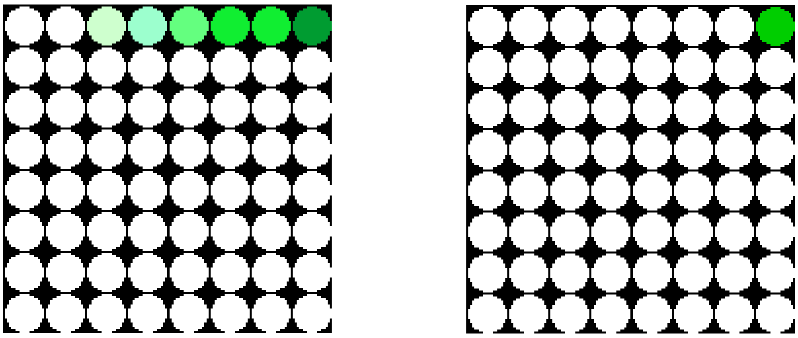

Figure 3. Schematic showing a stylised phosphor based display with persistence (on the left) and a zero persistence display (on the right).

6.2 Scanning Regime

Few displays illuminate all of the screen area at once, instead, most displays illuminate only a small portion of the screen area at a time, and rely on the limited temporal resolution of the visual system to give the illusion of a isotropically illuminated display. Although the first scanned televisual display, the televisor of Baird, scanned with a vertical fast scan, very early in the development of television it was arbitrarily decided that the display update scan would start in the top left of the display, scan quickly from left to right, and at the same time scan slowly from top to bottom to gradually illuminate all of the display. The only common modification was the introduction of an interlaced scan to reduce the visible flicker in the image, where two passes of the vertical slow scan are required to illuminate all of the display. This form of raster scan is the only form of scan used in displays that use a scanned frame update. Until fairly recently, this *status quo* was maintained because the scan used in creation, transmission and reception, as well as display, were identical. Thus very complex electronics would have been necessary to use an alternative scan at any point in this chain, and any changes would be against the huge installed user base. These days cheap microelectronics has reduced the cost of changing a scan pattern to an acceptable level, and the most appropriate scan can be chosen for image creation, transmission, reception and display, without compromise. Indeed, this is currently happening, as digital TV is created with a frame-grabbing camera, edited using a frame-by-frame linear editing tool, stored and transmitted using a difference-from-previous-frame encoding, and displayed using a traditional raster.

The conventional raster results in some display artefacts with DRI systems. Primarily these are associated with the zero persistence of the display, and involve the 'pickup' of the raster scan on saccade or in certain vibrating conditions, where a very bright line is seen on the display. This can become obtrusive. Different types of scanning regime are under investigation as suitable alternatives for the traditional raster. At its most simple, the traditional raster can be rotated. This gives no advantage over the traditional raster, but may be preferred for engineering reasons. It is worth noting that the conventional fast left-right slow up-down is usually more appropriate as saccadic eye movements are more likely in the horizontal than the vertical, particularly if reading is involved. If a resonant fast scan is used then a boustrophedonic raster becomes appropriate. Here the image is written with alternate left-right and right-left fast scans. This approach gives a higher vertical resolution and image brightness than if the line flyback is simply blanked. Another scanning approach is through the use of a fractal scan to write the image, such as a Peano-Hilbert space filling curve. This may require a higher frame refresh rate than the conventional raster to avoid flicker in the image, but could offer advantages under vibration, and it is possible that the scanning hardware would prefer such a scan. Finally, random, pseudo-random and chaotic scanning patterns seem to offer advantages in terms of less image break-up under vibration than seen with other scanning regimes, but again seem to require a higher refresh rate to give an acceptable image.

6.3 The visibility of the image in observers with reduced vision.

If the display is engineered with a small exit pupil then there are advantages in the readability of the display by individuals with poor vision. This would seem to mainly be due to the huge depth of field introduced by using a small exit pupil, but could include other factors (7)

6.4 Monochromatic sources.

The HF effects of using monochromatic sources remain to be fully identified. It has been postulated that speckle in the image may reduce visual performance. Furthermore, the waveguide nature of the photoreceptors may be particularly affected by monochromatic light. This remains a poorly understood region of vision.

7. CONCLUSION

Direct retinal imagery has the potential to replace conventional displays in many personal display applications. DRI offers potentially smaller size, lighter weight, lower power, and/or higher brightness than an equivalent conventional display.

Some practical optical engineering considerations must be addressed when designing DRI systems. These include the exit pupil size and whether to use pupil tracking, the light source(s) and how to provide the source modulation.

Some novel human factors considerations must also be addressed in designing a DRI system. These include zero persistence, the scanning regime, the effect of using monochromatic sources, and the effect of any exit-pupil - eye-pupil tracking on visual performance.

8. ACKNOWLEDGMENTS

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The Stakes and Ways for HF Assessment of Militarian Prototypes Bringing Techniques from the Air Traffic Control Field

Mr Louis Graglia, Ms Nelly Chouvy, Mr Dominique Soller
Bertin Technologies
Pole Facteurs Humains
Parc d'Activités du Pas du Lac
10, Avenue Ampère
78180 Montigny-le-Bretonneux, France

1 The ATM framework

The steadily growing air traffic, these last ten years, requires an evolution of an aging system, but which enables the present ATM to guarantee a very high security level of $10^{-6}/10^{-7}$. In this high responsability environment, the main changing point will be to give air traffic controllers smart control assistance tools, which implies to set up a computerized environment, based on operational needs.

This evolution breaks away from present work methods, which still use paper supports (strips), which may appear archaic, but which ensure the reliability fo the system.
This work method however, appears to limit the sharing of information between the different actors (controllers of various sectors, pilots…).

But in such a highly cooperative system, it is a main improvement of air controll security and efficiency in mutual awareness of the situation, by actors whose aims may at times be contradictory (the pilot has an individual point of view, whereas the controller has a global management of the traffic).

1.1 The cognitive model of the controller

In this complex environment, air traffic controllers have achieved an efficient dynamic compromise between the three following demands :

- **managing trafic** : ATC implies to make decisions in a state of partial uncertainty and diagnostics on fast-changing data, while having to manage continual interruptions, requiring complex memorization processes, such as restating the context of the task each time a pilot calls.

- **managing cooperation** : for security reasons, each control position is manned by several controllers. Therefore, controllers must cooperate according to flexible organization (implicit or expicit sharing of tasks). These cooperations are highly dependant on the material and human ressources available in the environment. On the global level, controllers of various sectors also have to constantly coordinate their actions (notably when they shoot a flight from a sector to another).

- **managing the HMI** : the interface appears a support of informations more or less easily detected or inerpreted, but it also entails mental processes. The pattern of activity is not determined only by voluntary research of particular informations, but also by the appearance of various alerting signals chosen by the controllers as significant according to the context. We must therefore identify those alerting signals in the present environment to imagine their replacement in a computerized envrionment, which implies to define a new way of working with an efficient linking of visual displays.

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On the controllers position, managing the workload relies on adjusting this compromise : when the wokload tends to grow, there is a conflict between these three demands, which may be managed by the controller either by modifying their control strategy (by optimizing security versus fluidity), or the sharing of tasks, or by reducing interface management (e.g. strips will not be fully completed).

Approaching the activity in terms of conflicts management is the main guideline while designing a new system. Concerning simulation, this approach leads to a high level of realism, as the assessment must not be restricted to the use of the interface : the aim of a controller is not to use a tool but to guarantee a good level of performance in terms of traffic security and air flow. Therefore, the assessment concerns how the interface impacts the management of conflictual situation.

2 The design process

2.1 Framework of the CENA

CENA, the French Air Navigation Study Centre, is responsible for promoting and designing advanced concepts required for the development of the future Air Traffic Control system within the European context. It is structured in several complementary divisions : the CENA produces prospective studies (on interaction technologies, on flow modelisation…) which support short term studies attached to operational contexts (design and evaluation of new tools for various controllers).

This structure is based on important simulation and development ressources which enables testing and validation of new concepts with operational centers. The close relationships of the CENA with the operational centers and agencies allows first, an easy access to real work situations (primordial for the initial expression of needs) and secondly, facilitates the controllers participation at different stages of the experimentations.

A central department of DNA (STNA) is in charge of designing, implementing and setting up the main systems and equipments. It acts as the prime industrial partner of the CENA.

2.2 The design paradigm

After many unsuccessful experiments, the idea of an entirely automatic control system has been rejected. No computer has ever been able to solve the totality of situation in a complex traffic environment. Therefore, the design paradigm is based on creating tools aimed at helping the controllers to focus their cognitive resources on essential points. The goal of automatisation today is to increase efficiency of mental processes (perception, memorisation …) and to delay their limits of degradation. Automatisation is no more thought as a way to progressively expell the operator from the process of decision, but on the opposite side, is a mean to optimise the operator efficiency ever more by enlarging the limits of his ability.

2.3 Different aspects of design process

- Expression of operational needs
- Definition and validation fo HMI principles (informations, dialogs…)
- Evaluation of the impact of the system on the future skills (including sociological aspects)
- Integrating human factors in the project management

The following parts will mainly develop the second point, although the human factor approach is implemented for each of those topics

3 HMI evaluation process in simulation (CENA, ICS department)

From a theoretical point fo view, two interactive complementary approaches are developed : an **analytical approach** (modelisation) and an **empirical approach** (analysis of activity in situation including the context). The first stage, based on cognitive and task models, is compared to an experimental stage which validates or corrects the various models.

3.1 Top-down and experimental process

This top-down process starts from the general aims of the study down to a practical definition of relevant data to be recorded.
The experimental process defines the « what to evaluate » and « how to do it » through four steps :

- targets of the studies and the hypothesis (or questions),
- experimental parameters,
- air traffic control situations (scenari) focused on problematic or critical fonctions,
- relevant data to be recorded.

3.2 User-centered methods

Controllers from five en-route control centers and from approach centers (mainly Aeroport de Paris) are asked to actively participate in the different stages of the design process :

- early implication of the users allows to test the concept so as to avoid pointless development work (utility).
- at each experimental stage, they identify the difficulties in using the HMI (usability).

4 Computerization

VIGISTRIPS : an application of the HF integration methods and tools in Air Traffic control. Moving from paper to computerised process

5 HMI principles and targets of studies

5.1 HMI principles

- 10 major principles defined within PHIDIAS program
- examples :

radar image
- contextual information (coding of map background according to configurations,…)
- filtered relevant information (by clusters, by problems,…
- …

5.2 general targets

- utility and usability of the interface,
- performance level,
- workload evaluation
- errors
- impact of the system on the cooperative processes,
- ….

5.3 Particular targets

- using of color,
- direct interaction with the label,
- …

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Human Factors Directions for Civil Aviation

Sandra G. Hart
Human Factors Research and Technology Division
NASA-Ames Research Center, Mail Stop 262-11
Moffett Field, CA 94035
USA

Abstract

Despite considerable progress in understanding human capabilities and limitations, incorporating human factors into aircraft design, operation, and certification, and the emergence of new technologies designed to reduce workload and enhance human performance in the system, most aviation accidents still involve human errors. Such errors occur as a direct or indirect result of untimely, inappropriate, or erroneous actions (or inactions) by apparently well-trained and experienced pilots, controllers, and maintainers. The field of human factors has solved many of the more tractable problems related to simple ergonomics, cockpit layout, symbology, and so on. We have learned much about the relationships between people and machines, but know less about how to form successful partnerships between humans and the information technologies that are beginning to play a central role in aviation. Significant changes envisioned in the structure of the airspace, pilots and controllers' roles and responsibilities, and air/ground technologies will require a similarly significant investment in human factors during the next few decades to ensure the effective integration of pilots, controllers, dispatchers, and maintainers into the new system. Many of the topics that will be addressed are not new because progress in crucial areas, such as eliminating human error, has been slow. A multidisciplinary approach that capitalizes upon human studies and new classes of information, computational models, intelligent analytical tools, and close collaborations with organizations that build, operate, and regulate aviation technology will ensure that the field of human factors meets the challenge.

Introduction

Projecting the future challenges of a field as diverse as human factors is a daunting task. Although inherent "human" capabilities are not likely to change, the "factors" with which they will have to contend are likely to change dramatically. The crucial role that human factors can play in aviation has received increasing recognition during the past 25 years, as thousands of articles, presentations, books, committees, regulations, and research programs attest. However, the majority of aviation accidents and incidents still occur as a direct or indirect result of untimely, inappropriate, or erroneous actions (or inactions) by apparently well-trained and experienced pilots, controllers, and maintainers. This trend continues despite considerable progress in understanding human capabilities and limitations, incorporating human factors into many aspects of design, operation, and certification, the emergence of new technologies designed to reduce the workload and enhance the performance of the humans in the system. Possible solutions to these seemingly intractable problems include more (or less) automation, more (or different) training, more (or less) information in the cockpit or control suite, and changes in the underlying philosophy and structure of the Air Traffic Management (ATM) System. We have moved from a very fragile system in which the safety was the sole responsibility of individual pilots to the current ultra-safe system where safety is "designed-in", regulated, proceduralized, and monitored. We have reached the point, however, where completely eliminating risk and predicting (thereby avoiding) the next accident may not be an achievable goal (Maurino, 2001).

The United States has enjoyed one of the safest and most efficient transportation systems in the world, but it is facing significant challenges. Demand for passenger and freight transportation is predicted to double in the next 20 years and triple in the next 50 years (FAA, 2001). The National Airspace System (NAS) is already approaching its capacity limits and environmental and economic challenges to American aircraft manufacturers and airlines continue to grow. The vision expressed by the Federal Transportation Advisory

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Group was of an “integrated national transportation system that can economically move anyone and anything anywhere, anytime, on time without fatalities and injuries that is not dependent on foreign energy and is compatible with the environment” (Federal Transportation Advisory Group, 2001, page 1). Since people will continue to play a central role in every part of the future NAS despite advances in technology, the solutions adopted to solve these challenges will surely include and impact the pilots, maintainers, dispatchers, and controllers who operate within the system. Thus the scope of issues that must be addressed by the field of human factors in coming years will be quite broad.

We have solved many of the more tractable problems related to simple ergonomics, cockpit layout, symbology, and so on, but have devoted little attention the problem of forging an effective partnership between humans and information technology (IT) within the context of aviation. Although IT will offer a wealth of opportunities that may necessitate redefinition of the roles and responsibilities between the air and ground and between humans and technology, human factors has been applied rarely, even as an afterthought, by developers of computer technology. The importance of the link between human factors and IT was recognized nearly a decade ago by the Committee on Aeronautical Technologies (1992) convened by the National Research Council to forecast aeronautical technologies in the 21st Century. This group predicted that information sciences and human factors would play a different and more fundamental role in aeronautics for the next two to three decades than they have in the past. They opined that application of this multidisciplinary expertise to improvement of ATM capacity and operations, flight system design, and alleviation of human error would result in safer and more convenient future air travel. More recently, the Federal Transportation Advisory Group (2001, p.10) suggested that the information revolution would be “as important to transportation as the invention of the automobile and jet engine” and that it would “improve safety and mobility of people and goods while reducing its impact on the environment and energy consumption”.

Environment

The next few sections set the scene for the remaining sections, outlining my assumptions about the environment in which pilots will be flying in the first quarter of the 21st Century. Although many legacy systems will remain, and most of the aircraft in operation today will still be flying, there will be significant changes in the design and philosophy of the NAS, the roles and responsibilities of flight crews and controllers, and many new technologies introduced into cockpits and control facilities. Ensuring the effective integration of pilots, controllers, dispatchers, and maintainers into this system will be the challenge faced by the field of human factors during the next few decades. Many of the underlying issues will be similar to those examined in the last few decades, because inherent human capabilities and limitations have not changed, and new issues will emerge in response to changes in the aviation environment and the arrival of the Information Age.

Motivation for Change

At the beginning of the 21st Century, the NAS is still remarkably safe (approximately one hull loss per million airline departures), although it is nearing saturation (see Table 1). In 2000, for example, more than one out of every four flights was cancelled, delayed, or diverted (Dillingham, 2001). That represents nearly 1.5 million flights! Such delays are predicted to increase to nine million hours per year by 2007 and to 25 million hours per year by 2017 (Creedon, 2001). The problem is most acute at 31 of the busiest hub airports in the United States. These airports account for 66% of the scheduled flights. More than 80% of the delays occur just 15 of these airports. The prospect of further increases in demand has prompted fears of future “gridlock” accompanied by an unacceptable increase in accidents. For example, the Federal Aviation Administration (FAA) forecast a 59% increase in passenger enplanements from 1999 to 2011 (Dillingham, 2001). As the Administrator of the National Aeronautics and Space Administration (NASA) pointed out (Goldin, 2001), the system has less flexibility to deal with unexpected, albeit inevitable, events as it nears its operating limits and isolated problems can create effects that ripple through the entire system. As the airspace becomes more

crowded, the margin for error will be lost that has cushioned the consequences of many errors and failures in the past. The human factors challenge will be to ensure that new ATM concepts, requirements for speed, consistency, and precision, information availability and format, and technologies in the air and on the ground are designed and operated so that they support and enhance the capabilities of the humans in the new system, not challenge them further.

Table 1: Demand on current system

	Daily Volume
Passengers flown	1.7 Million
Cargo carried	77 Million tons
Nonscheduled & GA	60,000 flights

Airspace

The NAS is a complex structure initially developed over 50 years ago that has evolved to accommodate increasing demands and new technologies. It is comprised of interdependent and interconnected subsystems, (e.g., automated data processing, surveillance, communications, navigation equipment), facilities (towers, terminal radar approach control facilities, en route centers), aircraft (transport, commuters, general aviation, helicopters), people (pilots, controllers, dispatchers, maintainers, regulators, inspectors), procedures, and regulations. The system is only now beginning to take full advantage of the opportunities offered by satellite communications and computer science. Attempts to modernize the Air Traffic Control (ATC) system in the last 20 years that fell short of expectations, insufficient runways at some airports, and inefficiencies in the system contribute to the delays. For example, aircraft are not able to operate independently on closely spaced parallel runways when weather conditions reduce visibility below minimum levels, thereby decreasing throughput by as much as 50%. Transitioning from approaches that lack vertical path guidance to those using both lateral and vertical navigation will improve the precision, reliability, and safety of the approach phase of flight. Adding the fourth dimension (time) to enable 4D navigation will further enhance efficiency. However, modernizing equipment and other system changes that can be implemented in the next few years are expected to alleviate capacity problems by only 5-15% (FAA, 2001a).

In response to growing concerns, the aviation industry has implemented over 50 initiatives to improve the capacity of the NAS (Dillingham, 2001), the Boeing Company announced its plan for comprehensive satellite-based navigation, and the FAA outlined an Operational Evolution Plan (FAA, 2001a). The FAA's plan incorporates promising research and proposals and outlines specific operational solutions with the goal of improving performance while accommodating 30% more traffic In cooperation with NASA and the aviation industry, the FAA plans to redesign airspace and aircraft routes, deploy new technologies, and move away from proceduralized air traffic *control* toward more flexible and collaborative air traffic *management*. The plan identified four key problem areas: (1) Arrival/departure rate, (2) En route congestion; (3) Poor weather conditions en route; and (4) Poor weather at airports. The immediate goal is to ease congestion at the worst choke points by re-allocating airspace and controllers proactively to sectors that are predicted to be congested and helping pilots avoid congested areas through advance warning and collaborative decision making. To facilitate this goal, NASA has developed and deployed software tools to aid controllers in scheduling and handling traffic en route, in the terminal area, and on the ground to reduce congestion and improve flow management. This work has been accomplished in cooperation with the FAA under the auspices of the Advanced Air Transportation Technologies (AATT) Program. Since a primary assumption of most visions of the future NAS is that critical operational decisions will continue to be made by humans, the AATT Program supports human factors research, evaluation, and modeling to ensure that the new tools and concepts will be compatible with human capabilities and limitations.

By 2004, the FAA's goal is to increase throughput by increasing flexibility (e.g., optimizing airspace design and implementing tools to enable "free flight"). Free flight refers to a more flexible ATM system that allows user-preferred routing and self-separation during en route portions of flight. Two free flight technologies have already been implemented (i.e., the Surface Movement Advisor and Collaborative Decision Making tools) and two others demonstrated (i.e., the User Request Evaluation Tool and the Traffic Management Advisor). As an example, a recent estimate suggests that Collaborative Decision Making alone will save as much as 10 million minutes of delay per year. By 2010, the goal is to implement satellite-based navigation, data link communications, and enhanced surveillance. Eventually, integrated air-ground systems

may ensure separation offering an “automated airspace”. It has been recognized that there is a major challenge facing the FAA in deploying free flight technologies, i.e., addressing the impact of modernization on the users (Dillingham, 2001). Using free flight tools will change the roles and responsibilities of controllers, necessitating a major culture change air traffic facilities and the relationships between pilots and controllers. If the 21st Century NAS is to achieve the goal of improved efficiency and capacity (while maintaining safety), human factors must play a key enabling role. Again, NASA will conduct the long-range, high-risk research to support these goals, in collaboration with the FAA and industry.

It is anticipated that these new capabilities will enable more efficient surface operations at existing airports, new routes to spread the flow of traffic across terminal area airspace, more flexible routing, and reduced vertical separation requirements. The Global Navigation Satellite Landing System will greatly increase destination options, by offering precise landing information from satellites instead of ground-based systems. Changes in the route structure will enable direct flights between non-hub airports flown by regional carriers, non-scheduled operations and general aviation, making practical the use of hundreds of regional airports. In the long term, building additional runways at existing airports and shifting traffic to underutilized airports offers tremendous potential for increasing capacity. NASA’s Small Aircraft Transportation System (SATS) program will work with the FAA and industry to develop the infrastructure necessary to support new capabilities for general aviation aircraft and enable the use of thousands of otherwise underutilized public-use airports (Holmes, 2000) that are not equipped with towers or radar surveillance. In the late 1990s, NASA’s Advanced General Aviation Transportation Experiments Program collaborated with the FAA and industry to design and flight demonstrate a small, smart, safe and efficient aircraft prototype to spur a revolution in general aviation. The SATS concept relies on GPS and a relatively inexpensive suite of electronics and sophisticated software to transform community airports. It is envisioned that these airports will offer near all-weather capabilities, “highway in the sky” approaches, virtual terminal area procedures, automated separation, current weather information, and a virtual tower capability. The goal is to increase access to aviation while simultaneously alleviating congestion at hub airports. One human factors challenge will be to ensure that the non-professional pilots flying these highly sophisticated aircraft into such “smart” airports will be adequately trained and supported by these revolutionary systems.

The current system for controlling traffic in international trans-oceanic airspace is relatively inefficient, relying on large separations between aircraft to ensure safety. There is no radar tracking or direct radio communication. Pilots and controllers have had to rely on vocal position reports from onboard navigation systems based recently on GPS and communications satellites. The current system is being replaced by the FAA’s Advanced Technologies and Oceanic Procedures Program, which will enable more efficient operations and the option of user-preferred routing. The Future Air Navigation System is already offering pilots and controllers data linked communications capabilities in trans-oceanic airspace.

There are a number of FAA weather initiatives that will benefit from and make use of systems developed by NASA, NOAA, and other organizations. Some of these initiatives have focused on developing more accurate observations, others on increasing coverage, interpreting the sensed data to develop accurate forecasts for more than two hours into the future, or disseminating the information to airline dispatchers, pilots and air traffic control facilities. Weather-related problems are one of the major sources of disruption in smooth and efficient traffic flow and either cause directly or contribute to rotorcraft, general aviation, and transport accidents. Accurate information about developing weather patterns will allow pilots and controllers to plan routes in advance to avoid potential problems or develop diversion strategies in flight well in advance of an immediate threat. These weather initiatives are likely to offer a host of human factors questions related to the value of displaying satellite images of weather systems, the best way to present weather projections and alternatives to both pilots and controllers, and how to train people to interpret and make decisions about the information. A key challenge will be to develop procedures and automation support for the new forms of collaborative risk assessment and decision making among controllers, dispatchers, and pilots that will be enabled by these weather now-casts and long-range fore-casts.

A long-range goal of modernization activities will be to enable precision approaches to every airport in the country (without reliance on ground-based equipment), a dynamically re-configurable airspace, and point-to-point routes without the need to follow predetermined corridors (Goldin, 2001). Some of the features of the

long-range plans proposed by the FAA and others (see, for example, Ertzburger, 2001) are listed in Table 2.

Table 2: Characteristics of the future system

Goal	Future Characteristics
Flexibility	Dynamically reconfigure sectors, runways, taxiways, and restricted airspace to avoid congestion, weather
Efficiency	All-weather surface movement, direct routes, reduced separation requirements
Collaboration	Among controllers, pilots, and dispatchers
Distributed responsibility	For maintaining separation, adjusting routes in flight
Strategic roles	Route re-planning, assuring separation, flow management
Options	User-requested routing, less reliance on ground-based equipment, non-hub airports

A variety of efforts to automate controllers' tasks are envisioned at the beginning of the 21st Century. Automation of handoff, coordination, and flight strips is underway already. Decision support tools are being developed to assist controllers in strategic conflict detection and resolution, sequencing and spacing traffic, and traffic management. Tactical conflict detection and resolution and clearance delivery require infrastructure support and so will not be available for some time. All of these rely on implementation of advanced communications, navigation, and surveillance technologies to provide required information at rates and levels of accuracy never known before. To take advantage of this wealth of opportunities, pilots and controllers will need new information sharing and display capabilities, decision aids, revised procedures, and appropriate training. The human factors challenge will be to ensure that humans are not relegated to the roles of problem solver (brought into the loop only when automation fails) and integrator (of the output of piecemeal decision support tools).

Safety

Despite growing concerns about capacity, it is still true that "safety considerations must have absolute veto power" (Lauber, 1991) over the solutions that are adopted. In 1997, then Vice President Gore chaired a commission that outlined the administration's concerns about future decrements in flight safety (White House Commission on Aviation Safety and Security, 1997). Even if the rate of hull losses per million departures remains constant in the next 25 years as it has over the past 25 years, the absolute number of airline accidents is projected to increase to unacceptable levels as the number of flights doubles or even triples. There could be one hull loss every week if the rate remains the same by 2017 (Gunther, 2001)! Similar trends are anticipated for general aviation. And, although accidents are relatively low in many parts of the world, they are orders of magnitude higher elsewhere. (see Figure 1)

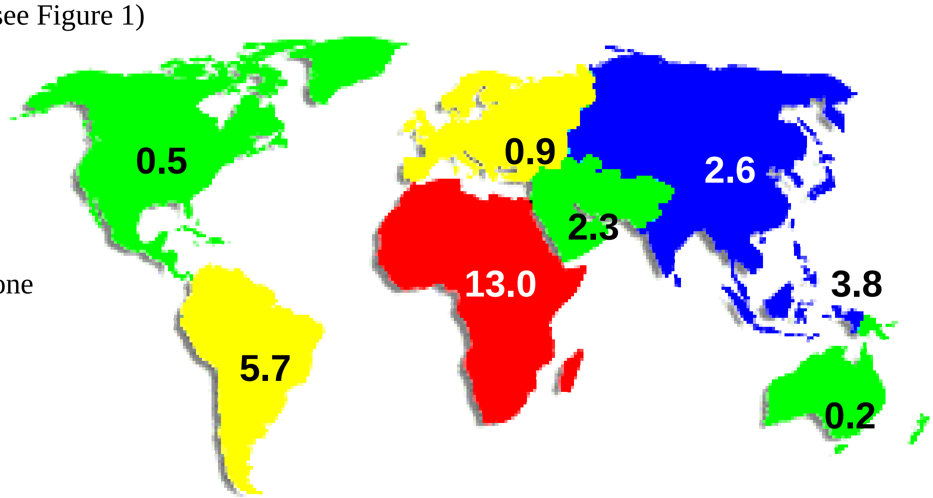

Figure 1: Hull losses per one million departures (Flight Safety Foundation)

In response to the challenges outlined in the Gore report, NASA initiated the Aviation Safety Program (AvSP) in 1998. Research and technology will address accidents that involve hazardous weather, controlled

flight into terrain, human error, and mechanical or software malfunctions (Lewis, 2000). Each element of the program will develop prevention, intervention and mitigation technologies, targeting key causal factors. Because traditional methods of assessing safety are not sufficient to identify vulnerabilities that may lead to a future accident alone or in combination, AvSP will create system-wide measures of the health, performance, and safety of the system and models to predict the impact of potential changes. Other elements of the program develop technologies, such as health and usage monitoring and synthetic vision systems, targeting specific links in the chain of events that might prevent future accidents.

In response to the same challenge, the FAA launched Safe Flight 21, a government/industry initiative that will develop and demonstrate surveillance, communications, and navigation technologies essential to the evolving NAS. Cockpit tools will supplement existing visual navigation aids and controller communications to assist pilots in accurately determining their position on airport surfaces, allowing them to taxi safely under low visibility conditions. Some technologies being demonstrated and evaluated include Automatic Dependent Surveillance Broadcast (ADS-B), Global Positioning Satellite (GPS)-based approaches, transmission of weather information to cockpits, and digital data link. Although recognizing the central role of human error in aviation accidents, both programs have focused primarily on the development of technology solutions such as acquisition, interpretation, and dissemination of weather data, synthetic vision, integrated health and usage management systems, fire-resistant fuels, and so on. One element of the NASA program has made a significant investment in addressing the most pressing safety challenge of the 21st Century, eliminating human error. The goal is to develop integrated computational models that can predict the impact on human error of new designs or procedures and identify situations in which errors are most likely. The training element of the same program will address human error as well by improving pilots' abilities to avoid errors and manage the consequences of those that do occur. The more immediate human factors issues addressed by AvSP benefit from the scientific foundation provided by NASA's Airspace Operations Systems (AOS) base research program. As Airbus Vice President for Safety pointed out, "the best way to reduce accidents is to improve human performance." (Benoist, 2001) Some of the "rules" he cited that pilots should follow to ensure flight safety include knowing the locations of your own aircraft, other aircraft, and obstacles and loss of control. Airlines can contribute by implementing flight standards and accident prevention programs, mandating "stabilized approaches, enhancing flight training and maintenance programs, and using lessons learned.

In addition, the NASA AvSP is addressing potential root causes of incidents and accidents intrinsic to aircraft maintenance and inspection operations. Current capabilities in maintenance human factors products are limited. Outside of a few models for maintenance resource management (MRM) training and incident analysis, few commercially available products exist. Although an abundance of software tools for electronic documentation and database management exist, specific adaptations to maintenance requirements based upon human factors are extremely limited. In order to remain cost effective in an increasingly competitive environment, airlines will have to dramatically decrease maintenance overhead costs. NASA and its collaborators are developing modern technology to reduce these costs in areas including task/risk analysis and procedural development, MRM training, and advanced displays. They are developing and providing guidelines, recommendations, and tools directly to maintenance personnel and managers.

The difficulties pilots of all nations face when they conduct international operations are beyond the scope of this brief overview, but they must not be forgotten: At the beginning of the 21st Century, there are more than 800 airlines employing more than 150,000 pilots and 16,000 airplanes, flying into more than 1,350 major airports in more than 200 countries (Higgins, 2000). Language barriers will continue to pose problems, as will cultural differences in interpretation and goals within and among cockpits, airlines, control facilities and national airspaces. National differences in airspace structure, capabilities, minima, and flow management style will continue despite extensive harmonization activities.

Aircraft Capabilities

In the past 50 years, transport aircraft have changed in evolutionary rather than revolutionary ways since the introduction of the first commercial jet transport, the Boeing 707. The number of aircraft continues to grow; Higgins (2000) projected that the civil fleet will increase from nearly 14,000 in 1999 to over 26,000 by 2015. The rate at which new technology will enter the fleet is relatively slow, however; most of the aircraft

flying today will still be flying in 25 years and most of the aircraft in the 2007 fleet have already been built. The range of capabilities will continue to increase to include eventually unmanned air vehicles and direct access to space. Even within the air transport fleet, significant changes are nearing reality with two new aircraft designs that will fly more passengers farther, higher, and faster than ever before. The Sonic Cruiser envisioned by Boeing Commercial Airplanes Group will fly 300 passengers at just under the speed of sound, while the Airbus 380 will transport more than twice as many passengers in a double-decker configuration. One of the possible benefits of the projected fleet of 1200 Airbus "megaliners" (Tarnowski, 2001) may be a reduction in congestion at the airports they serve. If the growth of very sophisticated, easily flown GA aircraft becomes reality, new issues will be raised about how to integrate technologically advanced vehicles flown by relatively low-time private pilots into free flight/self-separation environment. Accommodating this mix of aircraft capabilities will require the adaptive, flexible approaches proposed by the FAA. From the air transport pilot's perspective one concern may be coping with a mixed fleet within their own airline (e.g., adapting to the very different philosophies instantiated in the cockpits of Boeing and Airbus aircraft or transitioning from a more traditional cockpit to glass cockpit). If nothing else, these differences pose issues for training and procedure development. It is also possible that differences in philosophy about control authority, automation modes, information availability, and defaults might be considered when establishing new roles and responsibilities between the air and ground.

Some of the new types of information that will be available for display on the large color LCD displays that are likely to be the norm in the 21st Century are listed in Table 3. Voice messages that might take approximately one minute of airtime, will be digitally encoded instead and transmitted over the Aeronautical Telecommunications Network in a fraction of a second. The benefits include more frequent position updates, better access to the channel at any point in time, improved message integrity, and reduced likelihood of interrupting a pilot or controller at an inopportune time. Some applications occurred during the 1990s (pre-departure clearance, terminal area service and weather information) and many others are anticipated in the 21st Century, moving in the direction of replacing all routine communications between the air and ground. Many of these systems rely on the very accurate position information and transmission capabilities offered by GPS and ADS-B and powerful onboard computer technology. Deploying these systems and fine-tuning the human interfaces will extend well into the next decade as will human factors requirements for changes in training and procedures within the cockpit and between the air and ground.

The case for automation has been made based on economics and increased throughput, and the trend will continue. Automation is generally low cost, light-weight, reliable, fast, and enables increased precision and repeatability. It allows the reception and transmission of whole new classes of information than previously possible. It is also required to meet the increasingly stringent demands of the projected ATM system. However, any workload reductions that have accompanied automation have been offset by concurrent increases in system complexity new regulations and constraints, and increased requirements for precision in navigation and flight control. IT in general will likely be a primary focus of human factors efforts in coming years, not simply automation of functions previously performed by humans. Continuing efforts to delineate functions that are more appropriate for humans and for automation and ensuring that each if aware of what the other is doing.

(1) Enhanced or synthetic vision systems that rely on imagery from sensors that can "see through" weather integrated with a synthetic version of the outside scene
(1) Extremely high resolution terrain database based on satellite photography
(2) Increasingly capable flight management, integrated caution-warning, and RNAV systems that will interface automatically with their ground-based computer counterparts; highway in the sky route depictions
(3) Sensor-independent approaches
(4) Electronic map displays that depict routes, other traffic, weather
(5) Electronic operational documents (paperless cockpits
(6) Current and forecast weather; weather hazard alerts
(7) Text displays of digital data link messages

Workforce

Just as operating in the NAS envisioned for the 21st Century will require new technologies in the air and on the ground, so may flying the aircraft and managing the airspace require new human skills. Attrition and projected expansion of commercial aviation will require a significant number of new pilots to enter the workforce in the next 20 years. Who will these people be? What qualifications should they have? How much experience and of what type? Will computer skills be as important as stick and rudder skills? In recent years, the primary source of US airline pilots has shifted from the military to general aviation. With the increasing demands for pilots, airlines will be hard pressed to compensate for the limited experience and training of new hires. The Air Transport Association in cooperation with the Airline Pilots Association has formed a Future Pilot Subcommittee to project the knowledge and skills of the people who will be applying for airline jobs in the next 50 years so the training departments will be ready for them. They are defining the skills and abilities that a low-time pilot applying for an airline job should possess. Their output will represent the industry's expression of the expectations they will have of anyone who wants a professional career in aviation.

The US is suffering a shortage of certified flight instructors. Most flight instructors now working in general aviation are themselves low-time pilots with only minimal personal experience and little training in how to deliver effective instruction. This problem raises the specter of general aviation pilots who are minimally prepared to handle the challenges of all-weather flying and an increasingly complex airspace.

By 2010, 40% of current air traffic controllers will be eligible to retire (Dillingham, 2001). Not only will a turnover of that magnitude pose hiring and training challenges, but it is also likely that the skills required of these new controllers will be somewhat different than the skills they have needed in the past. Since it takes as long as five years for a new controller to go through the training process and become fully qualified at some of the busiest facilities, addressing these issues should not be deferred.

Human Factors Focus

To enable pilots to operate in the 21st Century airspace, a host of new procedures and technologies will be developed. Additional runways at existing airports and closing gaps in arrival and departure streams will pose similar human factors problems - - as slack in the system is reduced, temporal and spatial precision requirements will impose new demands on pilots and controllers and require extensive use of automation. As the flow of traffic is distributed vertically and laterally around the terminal area, en route and terminal area structures will become more complex, requiring the development of automated decision support tools to aid controllers in exercising strategic planning as well as making tactical adjustments. NASA is already developing a suite of 16 such technologies, many more of which will be required in the future. At the same time that greater precision in executing flight plans becomes mandatory, both pilots and controllers will find themselves giving up the tactical roles they now play in exchange for more strategic roles and sharing responsibility for separation and route adjustments. Each increase in flexibility and freedom will bring with it new and more cognitively demanding requirements on both pilots and controllers. There will be a parallel shift away from the exercise of sensory-motor skills to more cognitive skills. Both of these trends require a much deeper understanding of how people acquire, process, use, and store knowledge. Even today, most of the human factors issues in aviation stem from underlying cognitive problems. A major focus of human factors research in the 21st Century will be to better understand these cognitive processes in the context of aviation and to use this information to specify simple but completely sufficient systems that can efficiently support the pilots and controllers of the future.

The field of human factors is likely to become even more diverse in the 21st Century than it is today. Some ergonomics work will continue to ensure that workspace designs are compatible with the users. Perceptual research will continue to better match and augment auditory, visual, and even haptic displays to human requirements. Developing a better understanding of human cognition and developing useful models will be a major focus, as will similar activities directed toward the assessment and management of risks in the context of individual and team decision making. The field of human factors will have a considerably greater impact if it offers useful information about what to display, what to automate, and how interactions should take place to engineering designers so that new designs emerge from human requirements rather than just the

availability of technology. Operationally-focused development of training materials and techniques and operational procedures is likely to continue. As the field of human factors continues to have more to offer, it is likely it will play a more significant role in regulations and certification. A likely shift in focus for the latter will be toward the human factors implications of computer aiding (e.g., expert systems, intelligent tutors, decision support tools, and so on) and automation. In-flight monitoring of crew state may become a reality, necessitating the development of scientifically sound methods of regaining diminishing alertness. The following sections review some of these predictions in more detail, linking the driving forces mentioned above to likely roles that will be played by the field of human factors.

Automation

When the Boeing B-757/767, Airbus A-310/320, and MacDonald Douglas MD-80 models were introduced into service in the 1970's, so-called "glass cockpits" and increasing levels of automation prompted a rash of articles listing concerns and making dire predictions. In 1980, the US Senate Subcommittee on Aviation identified cockpit automation as one of the leading safety concerns in the decade ahead. Between 1980 and 1995, government and industry hosted numerous symposia, and workshops, created a National Plan for Human Factors (FAA, 1995) and formed a task force to address industry concerns (FAA Human Factors Team, 1996). The National Transportation Safety Board (NTSB) cited "automation" and faulty crew/ automation interaction as contributing factors to an accident for the first time in 1984 (Lauber, 1991). This accident involving a DC-10 flown by SAS was followed by the near loss of a B-747 flown by China Airlines and two accidents involving A320s, prompting another flurry of articles and dire predictions. This time, however, a growing body of information existed about automation that had been developed by industry, government, and university researchers (see, for example Billings, 1991; Wiener, 1988). Its is also worth noting that many of the accidents blamed on "automation" in the popular press might be attributed more accurately to faulty interface design, inadequate training, or poorly designed procedures than to the automated function *per se*.

Definitions of automation have changed and evolved as have the technologies themselves and their users' comfort levels. Hart and Sheridan (1984) defined automation as the use of a computer or any other machine to perform a task that might otherwise be performed by a human; the process by which essential functions are performed with little or no involvement by an operator. Another definition refers to the use of machines to monitor the performance of humans (Wiener, 1988). This particular application of IT has enormous potential once it is possible to infer intent accurately from measurable behaviors. Automation can be a servant, relieving humans of tedious tasks or, at the other extreme, replace them entirely (Wiener, 1988). It can be a boon to safety or a threat, reduce workload or increase it, improve performance or degrade it and so on (Lauber, 1991). To some extent, the existence of automation and its perceived impact is in the eyes of the beholder. In aviation, the term is often reserved for tasks that were once performed directly by a pilot or controller; other terms are applied to new functions people have not performed before. On the other hand, some functions have been automated for such a long time, and the possibility of deliberate or conscious control is so remote, they are no longer considered to be automation. As Wiener (1988) pointed out, it is "easy to forget the less spectacular equipment that is quietly and efficiently doing its job." It appears that pilots worry about "automation" when they no longer know what it is doing or feel they have lost control. In fact, computer displays, flight management and navigation systems, integrated caution and warning systems and the like are so numerous and so integral to the design and operation of advanced-technology aircraft that it is no longer appropriate to single them out and identify them with a separate label.

Billings (1991) outlined principles for human-centered automation that still offer a reasonable foundation although some adaptation may be required to accommodate the realities of 21st Century aviation:

Table 4: Principles for human-centered automation then and now

Original Principal	Twenty years Later
The human must be in command	The intent behind this principle is still valid. If pilots and controllers are responsible, they must retain the requisite authority. However, the motivation is no longer a fear that automation will fail (we have ample evidence that humans do that too), but recognizing the value of human creativity, flexibility, and ability to innovate that allows them to cope with entirely new situations. Automation must never be allowed to become “insubordinate”; pilots must always be able to regain control. To ensure this, managing automated systems must never be cumbersome.
To command effectively, the human operator must be involved	Although still true, the nature of such involvement will change. Relinquishing direct operation of control surfaces to automation with a few keystrokes is not relinquishing responsibility, but using the most appropriate tools to achieve a pilot’s goal. Pilots’ and controllers’ new strategic roles will re-define “involvement”.
To be involved, the human operator must be informed.	Level of detail and display media and contents may be different, but the principle is still valid. Given the explosion of information potentially available in the cockpit, the threat of too much information will be as great as that of too little. Appropriate organization, prioritization, and integration of the information will be essential. This is where the understanding human cognition will be particularly crucial
The human must be able to monitor automated systems	Humans must always be able to accurately assess what the system is intending to do and currently doing. Alerting and warning systems should be as simple and foolproof as possible, taking advantage of IT analytical capabilities.
Automated systems must be predictable	As the potential of IT grows, it will be difficult to resist the temptation to create systems that are so complex that humans do not fully understand their goal, state, or progress. Pilots and controllers will come to rely on automation once they have become comfortable with it. Such trust must not be betrayed by silent failures, invisible behaviors, or unexpected mode or state changes.
Automated systems must be able to monitor the human operator	The key here will be independence between the performing system (whether it is human or machine) and the monitor. To be effective, monitoring must consider whether the goal being accomplished is appropriate, as well as tactics. A challenge will be to develop systems that can monitor pilots’ or controllers’ functional states; warning them when alertness seems diminished.
Each element of the system must have knowledge of the other’s intent	Cross monitoring the intentions and actions of human and electronic members of air/ground teams will continue to be crucial. Automation can either cause a problem or solve it, depending on how it is designed. Automation must be both error-tolerant and error-resistant, depending on the circumstance.
Functions should be automated only if there is a good reason	As automation gains capability and reliability and human roles shift from tactical to strategic, “functions that should be automated” will be re-defined, but a balance maintained between an appropriate range of options and a bewildering excess.
Automation should be simple to train and learn	As will be discussed below, training should never be the solution for poor design. Making automated systems comprehensible to their users will continue to be absolutely essential and an important challenge for human factors

In 1995, the FAA chartered a team to investigate flight crew/flight deck automation (FAA Human Factors Team, 1995). While acknowledging the worthy objectives achieved by automation (e.g., reducing crew workload, additional capabilities, fuel economy, improved safety), the team identified vulnerabilities in

flight crew management of automation and situation awareness that still existed. They suggested that these vulnerabilities existed because of interrelated deficiencies in the system, such as:

(1) Insufficient communication and coordination within and between organizations to identify problems, research needs, and information;

(2) Inconsistent application of human factors principles in design, training and operations;

(3) Insufficient criteria, methods, and tools to evaluate and resolve important human factors principles;

(4) Insufficient knowledge and skills among pilots, designers, operators, regulators, and researchers, coupled with reductions in investments that might remedy the problem; and

(5) Inadequate understanding of the influence of culture and language on the interaction between humans and automation.

The FAA has been addressing these recommendations since the report was published. However, many of the vulnerabilities identified still exist and new ones will accompany the introduction of new technologies in the air and on the ground. In fact, it is unlikely that the task will ever be "finished". The following are a few of the automation topics that will continue to motivate human factors research well into the 21st Century. A tremendous amount of information has been and is being gathered about what is going on. The challenge will be to identify and evaluate the potential threat of recurring patterns and disseminate this information to relevant organizations. Tools have been developed to identify and reduce the frequencies of "automation surprises" (Palmer, 1995; Sarter, Woods & Billings, 1997). The challenge will be to apply these tools and then to resolve any difficulties they uncover. It is still easier to agree that automation *should* be "human-centered" than it is to do it. Considerable work remains to be done in identifying and resolving issues associated with cultural and language differences. Continuing erosion of human factors budgets poses a growing problem and the well-coordinated human factors agenda between government agencies, manufacturers, airlines, and pilot organizations that existed 10 or 15 years ago (FAA, 1995) no longer exists. The Human Factors Team recommended means of addressing these problems through changes in investment priorities, research, improved design, training, crew qualification, operations and regulatory processes, developing new tools and methods, and regulatory standards. In the 21st Century, as before, the most effective ways of bringing about change require close coordination among all of the participants in the aviation community. The desire of this team that human factors becomes a core discipline in fight deck design, training, regulations, and certification continues to be a worthy goal for the 21st Century.

Few human factors issues associated with increasing use of IT in modern aircraft have been resolved. In fact, the number of unresolved issues is on the increase as new capabilities continue to be added in the air and on the ground. It is possible that the rapid development of highly automated aircraft has out-paced the abilities of pilots to comprehend all of their "behaviors" and of trainers to help pilots develop appropriate mental models of how these systems function. There is no question that there are instances when airplanes do something that surprises the pilots, when pilots do something that the airplane does not expect, and when they collectively do something that surprises a controller. As the number of automated features and their possible interactions with each other, flight phase, and pilot input proliferate, answering questions related to mode confusion or awareness become ever more critical. It is still true that the biggest threat of automation is placing yet another layer of authority that is both undependable and indecipherable between the human operator and the system for which he is responsible. As in the past, the technical feasibility of automating a function should not provide the only justification for doing so. Finally, silent failures and automation-enabled errors can stem from trivial actions (or those performed hours earlier) but have devastating results. For this reason, revisions done under time pressure must be cross-checked. Research is being performed at NASA with industry and university collaborators on this topic, with the goals of discovering how pilots' mental models about automated systems develop as they gain experience with them (Holder & Hutchins, in press) and identifying situations in which the current mode is in fact ambiguous (Feary, M. & Barshi, I., 1998; Feary, Polson, Mumaw, & Palmer, in press). One approach that has been taken is to evaluate pilot-automation interactions with control-theoretic analyses to predict the potential for automation-induced errors and identify procedural and training deficiencies. This research will suggest ways in which the systems might be revised to reduce any

ambiguity about what mode the aircraft is in at any point in time, training programs improved to ensure pilots develop accurate and useful mental models about the automation they will be using (Casner, in press), and procedures and policies revised to ensure consistent and appropriate use of automation.

The benefits afforded by the increasing mechanical simplicity of current- and next-generation aircraft designs and consolidation of hundreds of indicators and their controllers into a few multi-function displays may be more than offset by new complexities, however. Requirements for temporal and spatial precision imposed by economic pressures, changes in airspace organization, and the need to comprehend and use effectively the vast amount of available information are beyond the capabilities of flight crews without very capable onboard and ground-based support systems. Similar introductions of new requirements, new information and different forms of decision support and automation into control facilities will continue to make dramatic changes in controllers' jobs. It is likely that most of these changes will improve efficiency, as that is what they were designed to do. However, it is less clear what their impact will be on controllers' jobs, particularly when making flow- management, routing, and separation decisions collaboratively with dispatchers, pilots and computer-based support systems.

"Automation" will play an ever-increasing role in aviation in the 21st Century, but the focus will be on introducing intelligence rather than shifting of one function after another from man to machine, as in the past. A variety of microprocessors supporting artificial intelligence, expert systems, neural networks, electronic databases, and real-time information exchange between the air and ground coupled with continuing improvements in display and control technology require a new way of conceptualizing automation. The real benefits of the information revolution to aviation will be realized when it is no longer seen as a separate entity competing for the crew's attention and challenging their authority. For this to occur, human factors must work toward the development of a seamless, intuitive, collaborative interface between aircrews or air traffic controllers, the systems for which they are responsible, and the NAS. In a well-designed system, humans and IT will cooperate in a symbiotic fashion, each performing the functions for which they are best suited. As stated in Airbus Industrie's automation philosophy, should be a complement to the pilot, a means of helping him perform a task better. It must allow the pilot to have full authority over the system to achieve maximum authority over system (Tarnowski, 2001).

Routine, small-scale, well-defined tasks, performed automatically with little human intervention or awareness will reside in all levels of modern systems. Tasks that require perceptual or physical abilities beyond the range of human capabilities should be performed by machines. Computing, storing and recalling large amounts of data are best performed by machines, as are precise, continuous or repetitive tasks, and detecting small signals. Tasks that require long attention spans or that people do not like to do are candidates for automation. Since humans are essentially serial processors, automation might be introduced to alleviate situations in which multiple tasks must be performed concurrently or several critical events occur at the same time. Tasks that demand complex decisions or value judgments cannot yet be automated, although IT can offer aiding. Unpredictable activities require human involvement and only humans can serve as innovators or solve unique or unanticipated problems. Humans must continue to perform tasks for which rules and procedures are not established and should be allowed to perform tasks they enjoy. Finally, humans must be allowed the flexibility of choosing among automated features and the authority to intervene in their operations. As in the past, piecemeal automation will continue to be costly, confusing to the users, and difficult to train. The foregoing principles are not new (Hart & Sheridan, 1984), but seem to be still valid. The difference is that rapid advances in computational science have made nearly anything possible, but the field of human factors has yet to specify the human side of the equation with any degree of precision or completeness. To a very great degree, this is because a truly generalized philosophy for designing, implementing, operating, and training automation does not yet exist (Wiener, 1988). Airbus Industrie cockpit designs are based on a set of guiding principles and have the great virtue of cross-fleet consistency. However, such benefits may be mitigated by barriers to incorporating new technologies, information, and airspace configurations and so on in order to maintain interchangeability with previous models. We have accumulated a lot of lessons learned, rules of thumb, best practices, and ways to avoid pits into which we have already fallen. However, the half-life of these lessons from the past will continue to decline at the same (accelerating) pace as that of computer

technology. The only solution will be to design automation, in fact the entire cockpit, based on a coherent, human-centered philosophy. Without this, pilots will continue to wonder "What is it doing now?"

As microprocessors have become integral to our daily lives, their "intelligence" is no longer a separate function but an essential and integral element. The same is true for aviation; "automation" has moved far beyond mechanical aids that relieve pilots of the need to enter continuous manual adjustments to maintain a desired altitude or remind them when they have exceeded that altitude. IT offers intelligence at breathtaking speeds, but it will be of little value if the information provided is not what a pilot or controller needs to know at that time and is difficult to find, understand, or use. Layers of intermediate systems between the pilot and the aircraft's control surfaces reduce the frequency of physical inputs and the force required but the cost may be that some of the actions taken by these systems are unexpected and undecipherable by the crew, offering new opportunities for pilot and controller errors that make take forms we can not yet conceive. Thus, the human factors challenge will be to answer questions about how to introduce safely new technologies (especially when they are "just" software and not even visible) and ensure they do not present their human operators with unpleasant surprises. There is a significant need for a comprehensive certification philosophy for automation.

Multi-national government/industry committees have been formed, such as the Flight Guidance System Harmonization Working Group to update the air-worthiness rules for autopilots, flight directors, and auto-thrust functions. Some of the issues addressed include mode awareness, mode behavior, and disengagement behavior (Abbott, 2000). The Air Transportation Association Human Factors Subcommittee on Automation (Chidester, 2000) is identifying problems with existing system, knowledge and policy gaps, and performance and training standards for next-generation systems. Some of the issues they have addressed include the importance of clearly stated automation policies for each type of aircraft in an airline's fleet, improving pilot's transition from aircraft with one automation philosophy to another, and proposing standards and solutions to airlines and manufacturers. The human factors community can work with these and other groups to ensure that the marriage between humans and computers in aviation is a happy one.

Table 5: New technologies and changing roles

Capability	Examples
New sources of information	ADS-B, GPS
New types of information	Satellite weather images, automated interpretation
New air/ground communication	Data link
New responsibilities	Free flight, self-separation
New requirements for precision	Arrival time, low-visibility taxi
New navigation concepts/procedures	CTAS, 3D/4D RNAV

Interface Design

The move toward glass cockpits interfacing with increasingly sophisticated ground-based and airborne computational systems will continue, although steam-gauge models will continue to fly for some time; 40-45% of the aircraft that will be flying in 2007 will still have some electro-mechanical instruments. Improving the pilot/vehicle interface has been a significant focus of human factors research since World War II, and it is likely that this type of research will continue into the 21st Century. However, the focus will shift from human-*machine* interface to human-*computer* interface and from the field's rather narrow focus on the flight deck to encompass other people and functions in the NAS. Digital technology has been a major impetus behind recent advances in aviation in the air and on the ground. At the beginning of the 21st Century, airborne computers have enabled fly-by-wire control systems which have, in turn offered the option of new types of flight controls, integrated flight management systems, sophisticated caution and warning systems, digital air/ground communications, and glass cockpits offering infinite possibilities for displaying and managing information. It is likely that the design of glass cockpits and input devices will evolve to accommodate the capabilities listed in Table 4.

Each of these new capabilities or requirements imposes its own human factors challenges as well as the need for integration with other air or ground systems. In the future, intelligent cockpits will be able to monitor and adapt to their environment and to the individual operator, ensuring safety and comfort and support vehicle-centric route optimization, ensuring system-level efficiency (Federal Transportation Advisory Group, 2001). Regardless of the economic, capacity, or efficiency benefits such advances enable, safety concerns must remain paramount. This will be as central a concern in the 21st century as it was one or two decades ago when automation seemed to be as much a threat as a benefit (Billings, 1991; Lauber, 1991; Wiener, 1988).

As new cockpit technologies are introduced, improved methods of measuring crew performance, predicting the impacts of new types of failures and unforeseen interactions on crew and system performance and establishing criteria will be needed. As the range of possible technologies and interfaces continues to grow and ways to extend human and system capabilities proliferate, it is impossible to predict what combinations will come to represent future "normal" operating conditions in different flight phases. Human factors research must take its legitimate place beside engineering disciplines focused on guidance, control, propulsion, structures, materials, and so on and provide the types of information designers need to ensure that human considerations are included in the next generation of vehicle designs. The human factors field must "develop a better understanding of human behavior and performance" and pursue a "human-centered systems design and operations policy that will enable transportation systems to adapt to their human operators rather than depending on operators to adapt to them" (Federal Transportation Advisory Group, 2001).

The introduction of these technologies will take place in a new context - - pilots will control their aircraft and controllers will issue clearances; both will monitor the system through intermediate computers rather than through mechanical linkages or spoken clearances. Furthermore, both pilots and controllers will move into the roles of systems monitors, necessitating a hard look at what information they really need to have and how best to present it. The shift away from direct control, communication, and monitoring will continue to erode pilots' and controllers' situation awareness unless new methods of keeping them engaged are developed. It is easier to maintain situation awareness when physically and mentally engaged in performing a task than simply monitoring its performance. Crew must be advised whenever an unexpected event occurs or a system changes its operational strategy automatically (Tarnowski, 2001) Display technology and computational power are sufficiently powerful and flexible at this point that there is no reason for systems to be designed around hardware and software limitations; interfaces to computer-based systems can be designed to be compatible with the way users think. Such options as natural language input, pointing, and other possibilities enabled by graphical user interfaces offer a wealth of possibilities. However, it is not clear whether the desktop metaphors that dominate the computer industry are appropriate for aviation. This is a fertile topic for human factors research. The challenge will be to design cockpit interfaces and control suites that are compatible with the way pilots or controllers think about the tasks they are performing and support the task at hand.

At the same time that pilot and controller responsibilities are undergoing changes, so will the means by which they communicate with each other. Human factors considerations have been and will be an important in resolving issues such as error protection, ease of use, vocabulary or terminology and operator acceptance. For example, NASA has been conducting research on the human factors implications of data link in cooperation with the FAA for a number of years (see, for example, Mackintosh, Lozito, McGann, & Logsdon,1999). Some of the issues that have been investigated in the past include the impact of loss of "party-line" information when air-ground communications are no longer over-heard by other pilots on the same frequency, mixed media messages, message timing, and revision of procedures. It is very likely that many more human factors issues will arise as data link is used for more functions and by a higher percentage of aircraft.

Increasingly, 21st Century cockpits will rely on large flat-panel displays with amazing graphics capabilities that offer the pilots the option of partitioning the display area into different windows. Computer-generated symbologies and graphics may coexist with pull-down menus and video or sensor imagery during different phases of flight. Head-up Displays (HUD) may be superimposed on the external scene to provide guidance cues to enable low-visibility landing, prompting the need for research to address critical issues related to management of attention between the forward scene and superimposed symbology (see, for example, McCann, Lynch, Foyle, & Johnston, 1993; Wickens, 1997). The HUD hardware and guidance system may

serve as an enabling technology for other new features, such as synthetic vision and color symbology and new operational capabilities, such as low-visibility surface operations. Simply managing the available information and display options could easily monopolize pilots' attention and time. A crucial human factors question will be to address the relative pros and cons of such flexibility. Numerous standards-development groups are working with regulatory agencies in the US and Europe to specify, among other topics, human factors requirements for multi-function, vertical, weather, and moving map displays, data link systems and cockpit displays of traffic information based on ADS-B (Abbott, 2000).

Electronic map displays, present in a plan or perspective view, will integrate navigation data from many sources with graphic depictions of terrain, the location, status, and intention of other aircraft, and weather conditions. The graphical user interface will enable flight re-planning using an intuitive interface. One example of such a system is being developed at NASA under the AATT Program (Battiste & Johnson, 2000) to facilitate the pilots' participation in free flight and self-separation. A prototype enhanced cockpit situation display has been developed that depicts surrounding traffic, dynamic 4D predictor symbology, and a color-coded conflict alert tool. It also offers graphical route assessment and re-planning tools for developing flight plans that avoid conflicts. Such flight plan modifications are submitted electronically for controller approval and data linked to surrounding traffic. Other new display concepts include side-looking vertical situation displays and video or sensor-derived views of the forward scene. The recently flight demonstrated Airborne Information for Lateral Spacing technology (Waller, 1998) and the Taxi-Navigation and Situation Awareness (T-NASA) systems (Foyle, Andre, McCann, Wenzel, Begault, & Battiste, 1996) are designed to improve the efficiency and safety of airport surface operations. These systems sense, disseminate, and display information about the precise locations of potential conflicts during landing and ground taxi to ground controllers and pilots. The introduction of these new technologies will have benefited enormously from the human factors input they have already received and will continue to receive in the future.

Other senses will be explored as avenues through which information can be transferred to pilots in the future. Since the cacophony of competing auditory alerts has been organized and channeled by the development of integrated caution, alerting, and warning systems and data link offers a diminution of radio communications, it might be time to take a second look at the auditory channel for presenting different types of information and tasks. For example, spatially localized auditory displays could portray a wealth of information while still allowing pilots to keep their gaze out the window. Research conducted by NASA demonstrated the significant utility of such a system for enhancing target acquisitions detected by a Traffic Collision Avoidance System (Foyle, Andre, McCann, Wenzel, Begault, & Battiste, 1996). Haptic displays tap yet another underutilized sense, vibro-tactile sensation. Given the heavy load placed on pilots' visual and auditory systems, human factors must explore and capitalize upon these other senses.

A joint government/industry activity is underway to develop a standard approach for designing both paper and electronic versions of flight and ground operating documents so that all of the departments in an airline draw from a common database, thereby eliminating confusion (Kanki, Seamster, Lopez, & LeRoy, in press). The group is also facilitating the conversion of manufacturer's recommended documents to the forms used by each airline. The "paperless" cockpit may become a reality, offering interactive databases that could include graphic images and video clips, replayed in response to pilot requests. Eventually such paperless information management systems will interact directly with flight management systems and assure technical accuracy and timeliness of performance calculations and projections. This change will prompt a host of concerns. Converting digitized information back into a paper copy so it may be easily read or filed is a simple task in offices (which, by the way, have not become paperless even though computers abound) but will be impossible in the cockpit. Just because you put text on a computer does not mean you have developed an electronic information system (Monteil, 2001)! If onboard computers are the *only* source of crucial information, then fast and intuitive access (particularly under stressful circumstances), easy navigation, and clear text or audio quality will be of paramount importance. Pilots will have to develop mental models of the structure of the information available in such electronic databases to be able to navigate through them. Given the increasing number of airlines flying aircraft developed by different manufacturers, there is a growing need to standardize the codes used for different subsystems and the way information is organized in operating

manuals. The Air Transport Association Digital Data Working Group is attempting to develop such an industry-wide standard (Travers, 2001)

Similarly, if the only way to enter a time-critical or crucial command is through the onboard computer, then the interface must be intuitive, fast, and smart enough to trap errors. Checklists displayed electronically and acknowledged by keystrokes or other entry will become the norm. A key human factors issue to be addressed in coming years will be whether the pilots' interaction with electronic checklists should be active or passive. A variety of input devices for this and other entry and control tasks are being considered. As with the display metaphors toward which new designs are gravitating, input device options also draw heavily on desktop computing (e.g., track balls, touch pads, joysticks, keyboards, etc.). A near-term focus for human factors research might be to identify the most reliable and usable input device or at least establish procedures by which alternative concepts can be evaluated during certification. More than 90% of the commercial fleet still use inter-linked, back-driven large-displacement controls (Creighton, 2000). One advantage of this traditional arrangement is the relative ease with which pilots can monitor each other's inputs and those generated by the autopilot. On the other hand, side-stick, fly-by-wire controls demand less effort by the pilot and may be the more appropriate interface for IT-intensive cockpits and the future airspace, as they explicitly reflect the changing role of the pilot and the nature of the systems controlled. In addition, fly-by-wire controls are the only way to achieve similar flying characteristics across an entire fleet (Tarnowski, 2001).

At the same time that both pilots and controllers are moving away from tactical control, they will be assuming demanding new strategic roles. Both pilots and controllers will need interfaces that support their growing strategic role; current philosophies and formats were designed to facilitate the tactical role they have played in the past. In much the same way that automation must be simplified, it is likely that the same trend will be required for controls and displays in the cockpit and in air traffic control facilities. When nearly anything is possible, editing and packaging information at the right level of abstraction may become the dominant theme. Human factors specialists with a strong background in cognition and deep knowledge of the operational issues will be in the best position to accomplish this task effectively.

A critical challenge will be to ensure interoperability among advanced ATM technologies and between advanced flight deck and ground-based technologies. At this point, major advances in the air and on the ground seem to have been somewhat asynchronous. For the entire NAS to function as efficiently and safely as envisioned, advances in pilot and controller capabilities, tools, responsibilities, and so on must take into account the impact each will have on the other. Furthermore, serious consideration must be given to the impact these technologies will have on dispatch, maintenance, and surface operations, again maintaining some level of parity and coordination so that all of the interrelated elements of the system will function harmoniously. Since each of the necessary functions rely on human operators, human factors can play a valuable cross-cutting function, ensuring successful operation of the whole.

Team Decision Making and Risk Management

Given the complexities encountered in trying to understand *individual* decision making, it is likely that research on *team* decision making will stretch well into the 21st Century. The human factors principles of shared information, distributed team decisions, and display formats that are perceptually and cognitively matched to the capabilities and requirements of the users are examples of the supportive role human factors could play in making the planned evolution of the system both safe and effective. IT is changing the nature of decision making, as it has so many other aspects of aviation. It has enabled the effective functioning of geographically distributed "virtual" teams comprised of humans and computers. Measures and models of team processes that have the same rigor as those developed for individuals do not exist. Principles for such shared decision making must be developed to ensure effective use of new opportunities. One example of such research is that being conducted at NASA by Judith Orasanu and her colleagues in airlines and academia (Orasanu & Fischer, 1997; Smith, McCoy, Orasanu, Billings, Denning, Rodvold, & Van Horn, 1997). Some of the topics being explored under the auspices of the AATT Program are the feasibility of sharing responsibility for separation and flow management between the flight deck and ground. The Collaborative Decision Making Program recently initiated by the FAA with participation of 30 airlines is a recent beneficiary of their research. Another topic that would benefit from human factors research would be to establish how

human and electronic members of teams establish shared mental models about how equipment works, situational awareness, tasks and procedures that are supposed to be performed and by whom, processes by which interactions take place, information to be shared, and so on. Defining the optimal balance between teams with a high degree of redundancy (who are likely to share mental models but lack breadth) versus those with considerable diversity (whose differences in mental models are offset by their breadth in skills and knowledge). New topics enabled by networked computers and extremely capable electronic contributors include whether or not team members are co-located and the mix of human and machine participants.

Risk is a topic that will receive increasing attention in coming years because of the important role it plays in decision making (Davison & Orasanu, in press). - - what it means in the context of aviation, how humans (and automated systems) predict and perceive it, what is an acceptable level, and how to manage it. Risk can be linked to economic benefit, mission success, safety, social and political issues, and the environment. Risk management relates to the prevention of negative consequences (along whatever dimensions are thought to be relevant) that might otherwise occur as a result of normal or abnormal variations in the functioning of human operators and machines and the environment in which they operate. In the future, automated systems may offer pre- and in-flight evaluation of risk based on their knowledge of the crew's experience with each other, the aircraft and the destination, the difficulties likely at the departure and destination airports, the length and complexity of the trip, hours since last rest, delays and weather that might be encountered, placarded equipment on the aircraft, time of day, and so on. Until that time, each of the humans in the system will make such risk assessments by themselves, often based on incomplete information and using no formal process.

For manufacturers, questions about risk revolve around how new technologies might reduce or mitigate the impact of risk. Regulatory agencies must be able to predict whether a new technology, procedure or regulation will increase risk inadvertently. Airlines seek ways to reduce risk through improved training, procedures, schedules, and so on. Researchers are paying more attention to the topic because they have realized that accurate risk assessment is a key requirement for successful decision making. Helmreich and his colleagues (Helmreich, Klinect, & Wilheim, 1999) classified the most prevalent threats to flight safety, or risk, that they observed in their analysis of data from Line Operations Safety Audits (LOSA) as: (1) *flight crew errors*, defined as a crew action or inaction that leads to a deviation from crew or organizational intentions or expectations and (2) *external threats*, defined as situations, events, or errors that originate outside of the cockpit or errors made by other humans in the system. LOSA data from normal flight operations, coupled with analyses of incident data from the Aviation Safety Reporting System (ASRS) suggest that pilot errors are an everyday occurrence. In audits of three airlines, for example, 60% of the errors committed by flight crews, many of which were consequential, and nearly 72% of the flight segments had at least one external threat (Klinect, Wilhelm, & Helmreich, 1999). Some of these errors and threats might have been predicted - - adverse weather, operational pressures, intentional noncompliance with procedures, incorrect use of automation - - while others might not have been predicted in advance. The former might benefit from design solutions or targeted training. The latter require research to identify situations in which they are most likely. Such threats and errors create an increased level of risk, particularly when they occur at the same time. Operational performance and safety are defined by the manner in which flight crews and ground personal recognize and manage risk, rather than by the absence of errors, equipment failures, external threats, and so on. Solutions are likely to involve improved training, design changes to resolve identified problems, advance warning about potential threats, and IT in the cockpit and on the ground to assess a controller's or flight crew's intentions and detect deviations from actions that support that intent.

In the 21st century, aircraft maintenance risk- and task-analysis tools must be further developed for maintenance human factors. The tools might include risk analysis of procedures to determine appropriate levels of inspection and to streamline inspection and engineering processes. Such procedural task and risk analyses should incorporate human factors principles of situational awareness, team coordination, communication, and resource management to improve the usability and structure of the procedures and supporting paper and electronic documents.

The challenge for the 21st Century will be how to tackle these questions in a context as dynamic, complex, and diverse as aviation. Organizations, designs, and training curricula that focus exclusively on

lessons learned will fail to anticipate risks that have not yet happened. Modern aircraft and ATM systems have become so complex that anticipating every possibility it not feasible. Furthermore, these systems incorporate so many levels of redundancy and failure protection that genuine risks generally represent the conjunction of multiple factors that nobody anticipated. Thus, the long-term goal will be to design systems and organizations that are resilient in the face of challenges to their integrity and operation. Although understanding how individuals cope with risk will be important, the crucial issue will be to understand ways in which teams of people who may be physically separated and have different goals, knowledge, and strategies for resolving potential risks can work together effectively (see, for example Davison & Orasanu, 2001). Furthermore, if the human and electronic members of a decision-making "team" do not share the same definition of risk nor assess the risk potential of the current situation or a candidate solution similarly it will be difficult to function collaboratively. Is "risk" limited to anything that threatens personal safety? Or might it include anything that might lead to less than perfect system performance, economic loss, or non-compliance with a company policy or regulation?

Individual, team, and organizational management of risk is one of the focal points of a proposed NASA Program, Design for Safety (DfS). A key element of this program will be the marriage of human factors and IT to improve aerospace safety by developing resilient systems comprised of humans, machines, and software that fail gracefully (if at all), adapt successfully to unforeseen events, and compensate for its own failures as well as those other components. Human factors must not only develop the underlying science but also translate their findings into the design tools, technology specifications, and the foundations for training and procedural improvements. In combination with human factors, IT will enable an "intuitive, high-confidence, highly-networked, engineering-design environment" that will "unleash the power of teams" to revolutionize the way in which new vehicles and systems are developed (Goldin, 2001). Collaborative design processes will benefit not only from more effective electronic networking, shared graphical interfaces, and libraries of previously developed sub-models and algorithms, but also a more effective method of capturing the design rationale for future use in training, procedure development, upgrades, and new designs. Again human factors can play an important role by defining not only how the design team might function but also the most effective ways in which to store the "corporate memory" of the design team for future use.

Human Error

Whether humans are in charge of, collaborate with, or support the IT that will dominate 21st Century aerospace operations, the specter of human error will continue to motivate the field of human factors. Human error and inadequate situation awareness remain the leading contributors to safety problems, accounting for 70-90% of the accidents and incidents across transportation modes (Federal Transportation Advisory Group, 2001). Human errors also contribute to operational inefficiencies, thereby reducing the overall performance of the system. In the aviation context, flight crew error has been defined as "crew action or inaction that leads to deviation from crew or organizational intentions or expectations" (Helmreich, Klinect & Wilhelm, 1999). As much as humans contribute creative intelligence and a unique ability to solve novel problems and cope with unexpected situations, they also contribute unforeseen, inappropriate, and incorrect inputs and fail to recognize similar failings on the part of their human and electronic partners. Unfortunately, training and experience do not offer a solution; experienced pilots make as many errors as inexperienced pilots, although they make different types of errors and do not manage them in the same way (Amalberti cited by Abbott, 2000).

Despite considerable effort we have not even scratched the surface of understanding why humans make errors and how to anticipate, detect, trap and mitigate errors. Increasing reliance on automation may lead to whole new classes of errors associated with over-confidence in its reliability and infallibility. Errors vary with respect to complexity, predictability, detectability, rate of emergence, and consequence. Response strategies vary with respect to time, solution availability, and constraints. The broad category of "errors" includes slips (the intention was correct, but the action was not), lapses (an item is missed), mistakes (the intention was incorrect), and deliberate non-compliance (Reason, 1990). Helmreich and his colleagues categorized operational errors as procedural, communications, proficiency, operational decision, or intentional noncompliance. These and other schemes for organizing information about errors do not get at their genesis, however. It is more useful to concentrate on defining the impact of an error, circumstances in which errors are

likely, and methods of coping with errors. The consequences of some errors are minor and have little impact unless combined in unfortunate ways with other circumstances. Other, “consequential” errors may place the aircraft in an undesired state or lead to further errors. A recent analysis of errors observed in 1506 operational flights suggested that 69% of the *consequential* errors involved proficiency and 51% operational deviations (although these represented only 5% and 6% of *total* errors, respectively). On the other hand, only 2% of the *consequentia*l errors involved non-compliance (although these represented 55% of total errors, Gunther, 2001; Sumwalt, 2001). Errors made by the pilots (internal errors) or by others, such as controllers, maintainers, or dispatchers (external errors) increase operational risk. These can combine with expected or unexpected “threats” to create situations in which further errors are more likely. Expected threats include such factors as terrain, predicted weather and airport conditions, while unexpected threats include commands from a controller, system malfunctions, or operational pressures (Helmreich, Klinect & Wilhelm, 1999). The consequences of errors usually depend on the co-existence of other factors and the crew’s recognition of and response to the error, making a neat mapping between cause and effect almost impossible. Recent analyses of 1506 line observations made by several airlines identified 2.48 threats and 1.5 errors per flight (25% of which were thought to have been mismanaged). Such threats and errors occurred on 85% and 58% respectively of the routine flights that were monitored (Gunther, 2001; Sumwalt, 2001). Nearly half of the errors occurred during the descent and approach phases of flight and more than a third of these were considered to have been mis-managed. These statistics are particularly striking, considering the fact that more accidents have occurred during this flight segment, historically, than any other.

As has been true in the past, it will continue to be necessary to look beyond the label of “human error” to understand why the error occurred to bring about changes that will prevent a similar event in the future. In most cases, such human errors are only one link in the chain of events that led to an accident and are the most visible evidence of a *system* problem, rather than an isolated human or machine failure (Reason, 1997; Woods, et al, 1995). The goal of minimizing human error will continue to exist. By controlling the growth of system complexity (at least from the perspectives of the humans who are responsible for operating the systems) and ensuring that systems are observable by the user, the likelihood of errors might be reduced. Reviewing and formally revising policies and procedures that pilots often modify or ignore in line operations would be far safer than to implicitly support such ad hoc “revisions” or label them as errors. In fact, Mr. Dan Maurino suggested that deficiencies in standard operating procedures might be at the root of *all* violations. ICAO standards that are scheduled to go into effect in November 2001 have been developed that reflect current checklist, briefing, and procedural practices. Such international standards may be effective in limiting the number of un-workable procedures that pilots simply routinely violate (Maurino, 2001). He believes that ergonomic and behavioral approaches for improving compliance have been done already. If we can figure out *why* people do not comply, a cognitive approach, there may be more success. This focus on improving standard operating procedures (SoPs) reflects their importance in line operations. SoPs can help in establishing a common plan, reducing ambiguity, reduce crew workload, contribute to better situation awareness and task sharing, and reduce the risk of conflicts (Speyer, 2001b). A good SoP or procedure enables operators exercise discretion and good judgment in making decisions and responding to unusual and unexpected situations.

It has become clear that it is impossible to prevent all human errors without removing the essential flexibility and adaptability that humans contribute to flight safety. Moreover, it is the negative consequence of such errors that must be eliminated, not necessarily the errors themselves (FAA Human Factors Team, 1995). Human factors research in the next decade is likely to focus on developing techniques to aid pilots in *managing* errors to minimize their potential consequences (see, for example, Orasanu ,J., Fischer, McDonnell, Davison, Haars, Villeda & VanAken, 1998). The attempt will be to keep errors under control, rather than eliminate them completely (Maurino, 2001); a more tractable goal. Pilots’ responses to their own errors have been defined as either “trapping” (detecting and managing an error before it becomes consequential), “exacerbating” (detecting an error but responding in a way that leads to a negative outcome), or failing to detect or respond to an error (Helmreich, Klinect & Wilhelm, 1999). Systems can be designed that improve human’s abilities to detect their own and others’ errors or that identify such errors independently. Such a system might reduce current differences in detecting and trapping errors as a function of crew position (Orasanu, *et al*, 1998). Smart sensors, microprocessors, and adaptive control systems will enable systems to monitor their own performance, the environment, and their operators to detect and recover from errors.

However, slips and lapses are easier to detect and correct than are mistakes. Continental Airlines has demonstrated the effectiveness of focused training on reducing errors and improving procedural adherence (Gunther, 2001). They have offered a one-day course on threat and error management to all of their 5500 pilots since 1997 that addresses such topics as managing errors, adhering to monitoring and challenging procedures, etc. One way of reinforcing the messages of the course was the practice of check airmen giving high grades for catching and resolving errors during check rides, acknowledging good error management rather than focusing on the fact that an error had been made. A particularly desirable outcome of future research would be to offer manufacturers and regulatory agencies objective and practical methods of evaluating the potential impact of a new technology or operational change on potential human errors.

Workload Management

The potentially negative consequences of sub-optimal levels of pilot and controller workload have been the topic of considerable human factors research since the late 1970s. This work was given impetus by the airline industry's move toward two-crew configurations and the US Army's plan to develop a single-pilot scout/attack helicopter. Research was focused initially on the development of workload definitions and measures and then on measuring and predicting the workload impact of new technologies and replacing functions previously performed by humans with automation (see, for example, Gopher & Donchin, 1986; Hart, 1986; Wickens, Sandry, & Vidulich, 1983). Most contemporary definitions of workload equate it with the "cost" of achieving task performance experienced by the human operator. Great confusion has accompanied the common practice of using the same term, "workload", to refer to the demands imposed by a task, the effort an operator exerts, as well as to the psychological, physical, and performance consequences of the operator's actions and to the naïve assumption that different measures of workload index the same entity. Models abound, but designers, manufacturers, operators, and regulatory agencies are most interested in the association between workload and performance rather than in theoretical issues; it is assumed that performance is most reliable under moderate workload levels that do not change abruptly. Later work (Hart; 1989; Raby & Wickens, 1994 Wickens & Hart, 1990; Sarno & Wickens, 1995). acknowledged the important role of operators' strategies in determining the relationships among task demands, workload, and performance. It became clear that apparently *human* limitations might instead reflect poorly designed controls, displays, and automation, extreme environments, or lack of motivation. Humans are remarkably flexible, adaptable, and capable. They can improvise, compensate for inadequate information and system or human failures, adjust to novel situations, exhibit graceful (rather than catastrophic) degradation, plan ahead, predict the future, and learn from experience. However, the cost of such a wealth of capabilities is the parallel threat of human errors that may occur in response to environmental stressors and excessive or prolonged workload. They may adopt different strategies for coping with a sudden increase in workload, for example. They may choose to process fewer tasks (e.g., defer activities, monitor fewer displays, ignore certain communications, consider fewer decision alternatives). Alternatively, they may perform the same number of tasks, but less completely or precisely.

Workload-related interruptions, distractions and forgetting to perform intended actions will be as likely to plague the humans operating in the future ATM system as they do today. Their combined impact on human error, and, thus aviation incidents and accidents had been well documented (Dismukes, Young, & Sumwalt, 1998). A recent field study found that responding to such interruptions and distractions forced pilots to interleave novel activities with habitual, well-practiced sequences, a high-workload, error-prone activity (Loukopoulos, Dismukes, & Barshi, in press). This issue will require focused human factors attention in the next century to help pilots and controllers manage the demands of concurrent tasks effectively. In the future, human factors researchers can use these data to determine whether such distractions and interruptions are rare events or inherent in the design and operation of the system and will continue to create unsafe situations. If the latter is true, then solutions must be developed to protect the human from this error-prone circumstance and to help them establish effective workload-, attention- and memory-management strategies.

The approach that has been followed in the past in commercial aviation has been to design systems that can be flown with an acceptable workload margin under every conceivable circumstance and to establish procedures for everything; a common-sense approach. There has been a shared belief that if everyone follows the rules, everyone will be safe and that those who do not follow the rules are not safe and do not belong in the

system. The underlying assumption has been that safety results from specification and supported the notion of total control (Maurino, 2001). However, growing bodies of data suggest that there are thousands of deviations from the rules in everyday operations. These deviations may or may not impact workload, increase risk and affect safety. This may reflect sound judgment calls by the pilots, the strategic exercise of prudent task, resource, and time management (or not). Given the enormous complexity of the current system, the infrequency of accidents, and the almost random causal chain for accidents that do occur, technology and training interventions to prevent future accidents are not obvious. It is clear that unanticipated disturbances and novel combinations events will continue to occur that cannot be avoided by engineering solutions. These facts and the gradual shift of responsibility for some functions to the air from the ground, and from air traffic *control* to air traffic *management*, will place new demands on the pilots that were considered in previous workload analyses. This will prompt the need for a fresh look at the field of workload assessment and prediction, with renewed emphasis on the cognitive aspects of workload and on the workload impact of new roles and responsibilities, such as those envisioned in free flight (Wickens, Hellebore, & Xu, in press). Another focus for renewed research should be the development of a better understanding of workload in multi-crewmember flight operations (see, for example, Orlady & Orlady, 1999) and developing measures and predictors of *team*.

Crew Interactions

The FAA defined Crew Resource Management (CRM) in the draft Advisory Circular on Crew Resource Management Training (FAA, 2001d) as “the effective use of all available resources: human information.” In the Advisory Circular for the Advanced Qualification Program (FAA, 2001c), CRM was further defined as “…an active process by crewmembers to identify significant threats to an operation, communicate and carry out a plan to avoid or mitigate each threat.” This definition goes far beyond the popular perception of CRM as leadership or teamwork training at best or “charm school” at worst. As currently defined, CRM training seeks to improve operators’ abilities to identify situations in which errors are likely, where “threats” from within or beyond the cockpit should encourage crew to exercise additional caution to avoid, trap, or mitigate subsequent problems. To be effective, CRM training must include team building and maintenance, information transfer, problem solving, decision making, situation awareness, and dealing with automated systems.

Organizations must incorporate MRM into their maintenance operations. New approaches to MRM intervention will target behavior change and skill development. Research will focus on development of recommendations and guidelines to assist operators in the implementation of MRM principles and return-on-investment assessment tools and benchmark comparison profiles will help audit the relative effectiveness of a maintenance human factors program (Kanki, 2000).

Much of the interface between the air and ground will take place between airborne and ground-based computers. Thus, these different systems form another sort of team that must function exactly as designed or human members of the airborne and ground-based teams must be informed. If free-flight concepts become reality, the relationship between air and ground will undergo even greater transformations. Questions about shared responsibility for separation assurance mediated by airborne and ground-based sensors, databases, and algorithms that evaluate, interpret, and project become crucial. This topic defines a new field of human factors research in which “team” decisions and behaviors involve humans (who may be physically separated by hundreds of miles and thousands of feet in altitude) and IT hardware and software through which information and control inputs must flow. Air/ground communications are already rife with misunderstandings and inaccurate assumptions (see, for example, Barshi, I. & Chute, R, 2000). It is likely that the confusion will increase, at least during the transition period.

The team required for safe and efficient flight in the 21st Century is likely to reflect the evolution of airborne and ground equipment, procedures, and the ATM system. In the cockpit, collections of microprocessors that gather, interpret, display and disseminate information, monitor and maintain guidance and control, and so on might be thought of as another member of the flight crew. Similar rules should be applied to the coordination between human and electronic members of a crew as have been applied to the

traditional (human) crew. Although human factors research will be needed to establish how this interaction might best take place, the following proposes a few ideas.

Someone must be in charge. In 1991 stated that this responsibility should remain the pilots. in the next few decades (Lauber, 1991). There is no reason to assume that this first principle will change in the 21st Century. However, the member of a cockpit team to whom responsibility for control over a specific function may be delegated at any point in time may well depend on who is most capable and available. This might be either a human or an electronic member of the crew. Other members of the crew must then offer independent verification that what was intended does, in fact, occur. The electronic support system must be designed to exercise the sorts of good team-membership skills that human members are trained to exercise in CRM programs - - that is, it must inform the team clearly and explicitly about its intentions, state, and so on. When serving in a monitoring or support capacity, it must convey critical information in such a way that other team members receive it. A similar team will be formed between air traffic controllers and the suite of computers and displays that assist them. As has happened with pilots, IT will change the controller's job. As their span of control is increased, they will move away from immediate, tactical engagement and assume a more strategic role. Again, roles and responsibilities may be flexible, but they must be explicit at any point in time.

Crew State Monitoring

Disruption of circadian rhythms by work schedules, travel across many time zones, and sleep disruption creates situations in which performance during waking hours may not be maintained reliably. As Graeber (1988) pointed out, the higher level human cognitive skills that are crucial for the judgment tasks that are the most vulnerable to the combined impacts of sleep loss, circadian de-synchronization, and boredom (and that automated systems can not yet make). While lower-level systems-monitoring skills may also suffer, onboard computers are more than capable of detecting and announcing most anomalies. Round the clock shifts for air traffic controllers pose some of the same problems. Questions about the relationship between flight safety, sleep loss, and disruption of the body's natural rhythms have been investigated by NASA since 1980 (Aviation, Space and Environmental Medicine, 1998). The NASA program was created to determine the extent of the problem, develop effective countermeasures, and translate scientific findings into operational use through education. As an indicator of the magnitude of the problem, surveys of 1423 commuter pilots found that 89% identified fatigue as a moderate or serious concern, and similar results were obtained from air transport pilots. In civil medevac operations, a disproportionate number of accidents occur at night (57%), far in excess of the frequency of operations that occur between dawn and dusk (Hart, in press).

The problem of fatigue among pilots remains; it was a topic long on the NTSB's "most wanted" list. Recently, the Air Transport Association created the Alertness Management Initiative to "enhance safety by reducing fatigue-related risks" through education, improved schedules, revised policies and regulations based on scientific research (Rosekind, 2000). One goal of these and other efforts is to develop methods of warning pilots when a loss of vigilance beyond some criterion is detected and providing pilots and controllers with effective alertness management tools. One of the issues under debate is whether the FAA flight and duty time rules should specify the total time a pilot can be on duty rather than focusing narrowly on actual flight time. Research is underway already at NASA, Airbus Industrie, and elsewhere to demonstrate the feasibility of monitoring pilots' eyelid closures and other markers of increasing sleepiness and decreased alertness during operational flights. Other techniques measure heart rate, temperature and other values to monitor and predict variations in pilots' circadian rhythms to enable a more proactive management of alertness. More effective chemical and behavioral techniques for managing alertness and establishing more effective schedules for rest, activities, and trips will improve pilots' abilities to function consistently and comfortably in the global aviation environment.

Continuing research and further development of sensors and data-interpretation algorithms will make routine monitoring of flight crew state possible in flight. Mathematical models, such as those under development by NASA, will be able to predict the performance capabilities of operators. Algorithms combining information about sleep history, recent schedules, time zone experience and so on will be able to predict periods of increased fatigue and decreased alertness. The result of this and other efforts will be to

provide schedulers with information about the impact of proposed schedules on the humans in the system allowing them to develop safer schedules from the perspective of the human in the system.

Selection

Just as operating in the NAS envisioned for the 21st Century will require new technologies in the air and on the ground, so will flying the aircraft and managing the airspace require new abilities. In the future, as in the past, the existing workforce will be expected to adapt to new interfaces, new sources and types of information, new procedures, and new regulations through formal training and on the job experience. The FAA has estimated that approximately 60,000 people begin pilot training each year. Of these, the airlines will hire approximately 4500 to replace pilots who have retired or resigned or augment their current staff (Swierenga, 1999). In the future, few new transport pilots will have received their flight training and experience from the military. The majority will have obtained basic flight training on their own and accumulated hours by flying their own aircraft, instructing, or flying for Part-91, regional, or foreign carriers. These pilots may join the airlines with considerable experience in advanced technology (which is entering corporate aviation quickly) or none (flying surplus air transports for under-capitalized regional or foreign airlines).

Since 1995, NASA's Advanced General Aviation Technology Experiment (AGATE) Program has been developing with industry and the FAA affordable new technologies, training systems, industry standards and certification methods for the next-generation, single-pilot, four-to-six place, general aviation aircraft capable of near all-weather operations. Starting in 2001, NASA's Smart Air Transport System (SATS) Programs will modernize GA operations within the NAS utilizing small, community airports. Among other goals, these programs seek to revitalize GA by developing vehicles that are easy to fly by and making training readily accessible. If these programs are successful, advanced technology features, such as all-glass cockpits and automated operations from ramp-to-ramp, supported by automatic separation in a tower-less, radar-less airspace will become commonplace in GA. This may create a very sophisticated cadre of new hires for the airlines in the next 10 to 20 years. They will have experience in cockpits characterized by a dense layer of IT that allows them to fly with the same ease that they would drive a car supported by an airborne internet and very "smart" airports. It is possible that they will have received at least some of their basic flight training over the internet and experienced embedded, computer-based training in the cockpits of their own aircraft. These pilots may not see the same dichotomy between "flying the aircraft" and "automation" that characterizes the pilots of air transport aircraft at the turn of the century. Their most salient capabilities may be related to their computer skills rather than their stick and rudder skills. In fact, it will be their computer skills that may define precisely how the aircraft flies, rather than any direct manipulation of the controls.

Similar trends are projected for the air traffic control workforce, 40% of whom were hired after the 1981 strike and will be soon eligible to retire (Dillingham, 2001). Identifying the roles that will be played by the humans involved in the 21st Century airspace and linking these to innate capabilities that pilots and controllers must possess is one challenge for the human factors field. A related challenge will be to devise valid and practical methods of identifying the presence (or absence) of the relevant qualities. Given the rapid rate at which the whole computer industry continues to change, the most important quality might turn out to be pilots' and controllers' abilities to adapt to technologies and environments that were not even conceived when they were first hired. It is also likely that many requirements will remain the same (e.g., intelligence, maturity, judgment, leadership, responsibility, good health).

Training

In the 21st Century, training must not be used as a solution for inadequate design as it was in the past. Wiener (1988) referred to training departments as "dumping grounds for problems created by cockpit design and management". A worthy goal for the field of human factors would be to develop, and be successful in implementing solutions to existing human factors problems and preventing new ones from occurring so that trainers are no longer faced with impossible tasks. Furthermore, training is a profession that requires expertise beyond the simple possession of experience with the target system. Candidate instructors must be given specialized instruction in how to convey knowledge and offer constructive feedback in order to create

expertise. Ensuring that pilots develop functional conceptual models of how advanced technologies function alone and in combination under different operational conditions requires a different focus than the current emphasis on procedural knowledge. In fact, there is evidence to suggest that many airline pilots do not have a complete or accurate understanding of the automation they will be expected to use when they leave training (Holder & Hutchins, in press). Airlines apparently accept this lack of conceptual depth because they assume pilots will gain the deeper understanding they need while conducting revenue flights.

As the design of the NAS evolves, requirements placed on the humans in the system will undergo significant changes that will, in turn, require new approaches to training. And, since IT will be essential to most of these changes, developing effective human interactions with computer-based technologies will become an essential goal of 21st Century training programs. The capabilities of many such computer-intensive, ground-based and airborne systems may be already beyond the average pilot's ability to understand fully and use properly. Unfortunately, it is very difficult for even the most motivated pilot to absorb all of the details of new systems capabilities, states, modes, and interactions during initial or upgrade training. It is also true that the time has not yet come that pilots can ignore the details of the underlying system or the types of information that are now the focus of basic flight training - - automation cannot yet offer failure-free performance under all circumstances that might allow that option. Training pilots to take advantage of the new opportunities and responsibilities offered by free flight will require careful thought. Developing and maintaining situation awareness will become especially important for pilots as they assume greater responsibility for maintaining separation and operating in a free flight environment. The topic has become an important element in airline training programs and NASA's AvSP is supporting the development of training modules targeting general aviation pilots.

Similar issues exist for air traffic controllers as well. On the job training methods upon which the system has relied may be inappropriate for developing the risk assessment, decision making, and strategic skills needed to manage the airspace of the future. The more flexible and dynamic ATM envisioned for the future will require that different skills are developed and interaction with IT emphasized. Innovative approaches for training air traffic controllers might be developed. Given the projected loss of controllers to retirement, more effective methods might be considered than current time-intensive on-the-job approaches, such as the use of very realistic control-facility simulators (such as NASA's Future Flight Central), immersive virtual environments, and distributed, web-based training programs.

In the 1980s, an oft-repeated fear was that basic flight skills would suffer if pilots came to rely on automation. It does not appear that the data support that position as much as suggest inadequate development and maintenance of the new *skills*. Loss-of-skill issues may have simply changed. Infrequently used levels or combinations of automation may be poorly understood, difficult to recognize, or forgotten. Similar issues may well arise as the number of automated or supported functions once performed by controllers increase; the increasing emphasis on strategic behaviors may result in the loss of traditional tactical skills. Helping pilots understand and use automation will be a critical element of future training programs. For example, in a recent analysis of pilots' mental models of autoflight and flight management systems, Holder and Hutchins (in press) found that pilots seemed to use a small set of simple conceptual models to understand how the automated systems controlled aircraft behavior early in their line experience with the aircraft. The models they used had not been presented in training, where procedural knowledge is usually emphasized, but rather were derived from models the pilots had developed early in their flying careers. To be more effective, human factors research might develop methods of grounding the training of new systems in the pilot's prior experience, developing explicit models of the underlying system and then helping pilots acquire an accurate cognitive model of the system during training. Instruction about cockpit indicators, pilot actions, and relationships between what pilots see and do would be more easily learned and remembered if linked to the underlying conceptual framework, thereby reducing automation surprises and mode confusions in line operations.

As mentioned above, significant progress has been made in the design and implementation of CRM training programs that address many key operational issues (e.g., decision making, risk assessment, leadership, communications, and so on). An issue that is the joint responsibility of trainers and designers is to create IT that can serve as an effective member of human teams and to train human crew members to look upon decision support systems and automation as just another resource to draw on. Another important issue is addressed in

the Airbus CRM philosophy. Pellegrin (2001) contrasted controlling *actions* that are immediate and based in the present to controlling *situation awareness*. To maintain situation awareness crews must make links between the past, the present, and the future, between experience, expectations, and the current state. It is difficult to maintain control and recognize developing problems without expectations. Most CRM courses focus on controlling actions, while they should also focus in controlling situation awareness; more than one crewmember increases the safety margin as there is more than one person to catch failures or errors and question goals, strategies for achieving them, and progress along the way.

Line Oriented Flight Training (LOFT) refers to the use of a training simulator and a highly structured script or scenario to simulate the total line operational environment. Ground-breaking research performed at NASA more than 20 years ago (Lauber & Foushee, 1981) initiated the eventual use of LOFT for initial, recurrent, upgrade and transition training by most airlines. NASA's work demonstrated the utility of LOFT for developing crew coordination, decision making, and leadership skills, as well as systems knowledge and aircraft handling skills in an environment that ensures relevance to line operations. An additional benefit is that emergency situations can be presented in the safety of a simulator but with considerable realism. Recent NASA research developed a training manual in use by many airlines that aids instructors in conducting facilitated debriefings to intensify the benefits of the training experience (Dismukes & Smith, 2000). Furthermore, training in a LOFT environment offers the potential for (as well as the requirement to develop) specifications and measures of *group* proficiency (Speyer, 2001a).

Human factors researchers can play an important role in developing new, innovative methods of providing training. Some aspects of *ab initio* or recurrent training might be delivered through interactive web-based programs. Cognitive models of relatively simple automation systems typical of general aviation aircraft can be developed through well-designed course materials. A deep understanding of the underlying principles developed very early in training has the potential of transitioning positively to later experiences with multi-engine, transport-category aircraft. As Holder and Hutchins (in press) demonstrated, pilots' models of automation reflect simplistic models of generic systems developed very early in their flight experiences. Training must focus on developing comprehensive understanding than simply facts a crew needs to know.

General aviation or professional pilots might be able to learn at home, benefiting from the potential availability of vast amounts of information, graphics, and so on. Such distributed training would enable general aviation pilots who live in very remote areas to access a wealth of information. Other possibilities offered by IT include embedded, onboard training systems whereby the vehicle itself could serve as a trainer. As an example, this function might be used in flight to rehearse or review missed approach procedures at the top of descent. General aviation aircraft might be designed to operate in a "trainer" mode in the hanger. In a cockpit where all of the pilot's interactions with the aircraft are through intermediate computers, expert systems could transform at least some cockpit displays and controls into a virtual simulator. Finally, the use of virtual reality for delivering compelling and realistic information to the pilot-trainee might be investigated; the immersive display capabilities developed for high-end video games already offer enormous potential that has yet to be tapped for this purpose. Human factors can play an important role in defining what aspects of training are candidates for these innovative approaches and by developing the interfaces, knowledge bases, and delivery to support them. Work is already underway at NASA in related areas. For example, an interactive tutor that could be offered on the internet to instruct pilots in the basic principles of managing automated systems for vertical guidance (Sherry, Feary, Polson, & Palmer, 2000).

Aircraft maintenance departments are currently characterized by out-of-date curricula, training programs that are not keeping pace with technological advances in aircraft design, workforce shortages, recent trends in the "bid system", and a move away from the tradition of apprenticeships. Each of these trends has led to problems within maintenance departments and contributes to the need for rapid, effective training of maintenance personnel and inspectors. In the 21st century, interactive virtual-reality devices will be used to train inspectors on proper maintenance procedures. These devises will augment existing classroom and on-the-job inspector training. Under the sponsorship of the NASA AvSP, work has already been initiated on this topic by Kanki and her co-workers (Kanki, 2000). They are developing a virtual reality system using hardware specifically developed for this purpose to be used for training (Gramopadhye, Bhagwat, Kimber, & Greenstein, 1998) and aiding maintenance personnel.

Operational Measurement, Simulation and Modeling

The development of system-wide measurement and modeling capabilities and establishing programs to assess what crews do during routine operations preview one of the trends that will characterize coming decades - - the availability of enormous quantities of data documenting every aspect of the day-to-day operations of the NAS. The human factors challenge will be to develop analytical tools, automated search and interpretation, and methods of presentation to provide useful information about what is going right, and wrong, in routine operations. Right now, we know a lot more about what has gone wrong (in specific instances that resulted in an incident or accident) than what is going right; we have performed detailed analyses of flights that ended tragically but ignored the vast number of flights that arrived safely at their destination.

Because traditional methods of assessing safety may not identify accident precursors, new approaches have been developed that rely on sophisticated analyses of incident data, monitoring flight crew performance in real time, and analyzing reports of operational difficulties to identify developing problems and track the influence of system changes on safety. Airlines have initiated a number of programs to obtain information about the frequency, nature, and consequences of potential safety problems in routine operations. Line Operations Safety Audits (LOSA) performed by airlines with support from the University of Texas and the FAA (Klinect, Wilhelm, & Helmreich, 1999) involve periodic, non-punitive, flight-deck observations. Subsequent analyses of these structured observations have revealed latent failures and recurring threats within an airline’s operations. Airline Safety Action Programs (ASAP) establish voluntary reporting by pilots, dispatchers and mechanics of safety concerns, allowing airlines to take corrective actions (FAA, 2000). Flight Operational Quality Assurance (FOQA) programs establish routine monitoring and reporting by airlines of significant events and exceedances to identify safety issues and trends (FAA, 2001b). These data, in combination with accident and incident databases and objective measures of aircraft parameters during line operations provided by systems such as the Automated Performance Measurement System (APMS), under development at NASA in cooperation with the FAA and airlines, offer unprecedented opportunities. APMS will offer a set of tools for flight-data analysis and interpretation to identify contributing factors and corrective actions for situations in which aircraft parameters exceed normal operating limits for that flight phase (Chidester, in press; Statler, 2001). The advantage of continual or random sampling of a representative subset of flight over voluntary reports is that the former offers the potential for developing valid trend information. With voluntary reports, it is never clear how many similar events have occurred, but gone unreported.

Using increasingly sophisticated data mining software, such as Quorum (e.g., McGreevy, 2001), detailed information about the host of disruptions to the smooth flow of cockpit activities that occur during every fight without further incident, but that might in combination result in a future accident, will provide meaningful content for future flight training programs. Quorum’s core capability enables the analysis, modeling, and relevance ranking of narratives. For example, 84 incidents relevant to the underlying causes of the American Airlines Accident that occurred near Cali Columbia (e.g., controlled flight into terrain, over-reliance on automation, confusion, international operations) were thus identified. A simple search of the Aviation Safety Reporting System (ASRS) database of 67,821 incident reports for “flight crew fatigue” would yield only 8 reports. Using the Quorum “phrase discovery” capability would generate a number of related phrases that would uncover an order of magnitude more relevant reports. Since most accidents involve a unique chain of events, prevention efforts must address the underlying factors that (apparently different) causes have in common. If humans are making the errors or creating the threats, information technology can be developed to monitor for and mitigate such problems in the future. If automated systems on the ground or in the aircraft or in the environment are creating threats that recur with some regularity, systems that are creating the threat might be modified or independent monitoring software developed to warn crews of impending problems.

Comprehensive models of the NAS will be a prerequisite to the efficient design of any new infrastructure concept or technology. High performance computing will enable the development of very large-scale models and simulations of the transportation system. These tools will enable the assessment of system performance, trade-off studies and potential implementation paths. However, the human factors community must develop very accurate and efficient models of human cognition and interaction with current and future systems to ensure that human limitations and capabilities are included in computational simulations of the

NAS. In addition, computational models and simulations have become indispensable tools for designers. Again, it has proven difficult to incorporate accurate representations of the human operators of the target systems to predict design-related impacts on performance. Under the auspices of several NASA programs, such as AvSP, modeling and simulation tools are being developed to enable the efficient production of design-relevant models that can predict the impact of candidate technologies and procedures on the performance of humans operating in realistically complex environments. One such model, Apex, will be useful for developing models that can identify situations in which the design of equipment and procedure might contribute inadvertently to operator errors. Apex offers tools to support the construction of theoretically innovative and practically useful models of a single operator performing realistically complex and demanding tasks (Freed & Remington, 1998). Apex offers theoretically neutral and modular sub-models of sensation, perception, short- and long-term memory, motor activities, behaviors, etc and a library of re-usable elements that can be combined to represent candidate control or display concepts in the context of complex, dynamic, and uncertain operating environments. A model of a human operator developed with Apex tools consists of cognitive, perceptual, and motor "resources", declarative and procedural "knowledge", and "behaviors" that range from simple, discrete responses to complex, cognitive functions such as planning, decision making, and situation awareness. Apex combines mechanisms for proceduralized execution of complex tasks in uncertain and dynamic environments that can be simulated using tools that are extremely flexible and require little knowledge of simulation technology or theory. The Man-Machine Integration Design and Analysis Simulation (MIDAS) has been under development at Ames for nearly two decades with primary support from the US Army Aeroflightdynamics Directorate. MIDAS offers an integrated human performance modeling environment in which notional user interfaces and procedures may be simulated, evaluated, and visualized in the context of a virtual operational environment. In the past, MIDAS have been used to model activities as diverse as military missions performed in an Apache helicopter, soldiers performing various activities wearing protective gear, civil tiltrotors and commercial jets flying approaches, 911 operators responding to emergencies, and Space Shuttle operations (Hart, Dahn, Atencio, & Dalal, in press).

Current models have difficulty generating realistic errors beyond those envisioned by the model's developer. (see, for example, Zachery, et al, 2001; Hart, et al, 1998). Different levels of abstraction will be required; available models of the airspace, vehicles, and human performance exist at extremely different levels and none readily scale up or down to facilitate integration with the others. Because key components of the current and planned NAS are so interconnected and interdependent, a virtual validation environment that addresses all of these factors will be essential to enable evaluation of future ATM concepts prior to implementation. Distributed and virtual simulation capabilities will allow designers, potential users, and regulatory agencies to make informed decisions about proposed changes.

Computational models that represent the ways in which distributed teams assess risk and make collaborative decisions do not yet exist, but will be required. Nor do available models adequately address the influence of corporate and national culture, motivation, personality and organizational factors. None can predict what factor(s) predispose people to commit what type(s) or errors, nor how errors are identified, trapped, mitigated. This issue is a particular problem when trying to predict the performance of a team composed of human and intelligent (but electronic) members who share (some) information, responsibilities, understanding, and capabilities. Another facet of the "team" issue is the need to develop tools and processes to support participatory design by teams of people who may be geographically separated as well as culturally and professionally diverse. This would enable more effective utilization of management and line pilots, experts in the developing airspace infrastructure, maintainers and human factors experts as well as the typical team of engineers and test pilots.

Conclusions

A host of interesting and important challenges face the human factors community of the 21st Century. Many of the "easier" problems have been solved, leaving important but very difficult goals, such as modeling human behavior, predicting and eliminating human error, defining and improving the ways in which humans and IT evaluate and take into account risk, and improving the functionality of culturally diverse groups. To be effective, human factors and IT must become more closely aligned, as computers and their interfaces will be

the primary means by which pilots and controllers will interact with each other and their respective environments. Automated sub-systems and intelligent advisors will elevate operators to the roles of systems managers who (strategically) direct the desired outcome rather than (tactically) control the system. This evolution will be successful only if the new roles of the humans in the system are carefully designed and supported. More than ever, human factors must be conducted by people with training in relevant academic disciplines, the practical tools to conduct meaningful research in applied settings, and knowledge of the aviation domain. Human factors should be the job of every aviator as well (Speyer, 2001a). Pilots must be given the knowledge, tools, and motivation to exercise good human factors in every revenue flight. It is time to re-invigorate the partnership between government agencies, industry and universities to ensure a steady infusion of innovative ideas tempered by an understanding of the issues and constraints. Government research laboratories, such as those operated by NASA, are in a unique position to ensure that this occurs.

Free market forces will dominate the design of the future air transportation system. The goal will be to develop a system that imposes as few constraints as possible while ensuring safety. It is important to recognize the relationship between potential risk and system output; if the system continues to require an increase in output without increasing resources, regulations and so on, then it is likely that it will have to accept a higher risk of violations, incidents, and accidents (REFERENCE). It is likely that in the future, as in the past, technology will be the driver behind system change and humans will have to adapt. The new system that is envisioned will be capable of giving different levels of service to aircraft with different capabilities; but it is clear that aircraft equipped with the most advanced technology will be rewarded, a clear incentive to continue the rush toward technology. Given the rapid pace with which technology availability and economic and safety pressures are causing rapid changes in aviation, human factors must rise to the occasion and incorporate new knowledge, techniques and subjects into their field. A number of activities are underway to improve the tools and criteria used in certifying advanced technologies in flight decks and to harmonize the US and European processes on many fronts. However these activities are a continuing processes, rather than single-point events, and it is likely that the role of human factors will continue to evolve as cockpits and ground-based systems evolve.

The Federal Transportation Advisory Group (2001) described the benefits of taking a global view of transportation, integrating highway, rail, and air travel into a seamless system of systems. One of the benefits would be elimination of mode-specific investments in research and development, to maximize public and private-sector investments and meet transportation needs. Since human needs, capabilities, and limitations are the one constant element across transportation modes, the field of human factors should champion this goal and take the lead in making it a reality. This advisory group further recommended that dramatic transformations in the transportation system will take place only if there are sufficient research investments in human performance and behavior and in new computer, information and communications systems. They recommended a significant increase in long-term, high-risk transportation-related research over the next decade to resolve pressing current problems and foster transportation breakthroughs for the 21st Century. This increase in investment is particularly important today as military investments in aerospace research and development have declined in recent years and aircraft development programs have been sharply curtailed, thereby reducing the flow of new technologies into the public sector (Goldin, 2001). Many of the challenges described above are not easily addressed by the private sector. As the primary source of publicly-funded aeronautical research and development in the US, NASA is the logical organization to take the lead in making such investments, in collaboration with the FAA, manufacturers, airlines, and universities. NASA's role should be to develop the scientific foundation for the design and use of current and future aviation systems. NASA should conduct the revolutionary, long-term research that the FAA and industry cannot perform and spin off research results to solve immediate problems.

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Design of Cooperative Systems for Emergency Situations : How to Take Into Account Implicit Activities?

B. Pavard
Cognitive Engineering Group
IRIT-UPS-CNRS
116, route de Narbonne
31062 Toulouse
France

SUMMARY

The goal of this paper is to analyse the role of implicit activity in cooperation and to define a methodology that allows us to take it into account the design phase of cooperative systems. Firstly, we will identify the most relevant cognitive processes in complex cooperative situations. Secondly we will analyse, using two field studies, how implicit and explicit activities interact in a real situation. This article supports the idea that the implicit activities are, contrarily to explicit ones, non deterministic and mandatory to achieve some tasks in unforseen environment. This has important theoretical and methodological consequences for ergonomic design. For example, if we accept this point of view its necessary to abandon the idea of a "zero fault" engineering in favor of a representation where it is necessary to combine optimally some explicit functionning modes (like procedures) with more open and self organised modes. This would allow the system to respond optimaly by self-organisation to nominal and degraded situations of the environment.

1 COOPERATION AND IMPLICIT (cognitives) ACTIVITIES

Cooperative activities are basic to human organisations. Its goal beside its emotional dimension is to improve individual performance and in some situations produce an overall collective performance more efficient than the simple sum of individual contributions. Cooperation is made possible mainly through verbal and non-verbal communications but also through communications mediated by external objects. Thus, understanding communication is is usually a prerequisite to the design of cooperative systems.

For example, in an emergency control room, agents may use postural information in order to assess the disponibility of their collegues before to trigger a speech act. A simple hesitation when acting on a command lever may be interpreted by the co-worker as an indicator of incertitude and produce a more secure analysis of the situation, etc.

Everybody in the field of working situations would confirm such facts or even found them trivial but it is a real concern to understand their real weight in the context of nominal or degraded situations. It is also a real challenge to design for such processes because we have at that time few theories or methodologies in order to understand such implicit behaviours.

The objective of this paper is to forward a unified model of cooperation where 1) the verbal and non-verbal dimension of cooperation are treated in a complementary manner and 2) actions on objects or artefacts in the environment are considered as communication acts and reasoning supports. Our approach is based on inferential theories of communication (Grice, Lewis, Sperber & Wilson). We consider that communication for cooperation cannot be treated as a deterministic model (like Shannon's theory of communication) but as an inferential model where all communication acts have to be interpreted in context. In this way, objects in the environment are also subject to into interpretation.

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We will propose two further ideas: firstly, it is the complementarity of deterministic and non deterministic processes that make the efficiency of cooperative complex systems; secondly, it is only this previous property that will result in a cooperative system that is able to respond in an efficient manner to degraded or unforseen situations.

1.1 Implicit activities: definitions

Implicit activities often refer to two concepts : the first one related to pragmatics (inferential theories) and the second one to work organisation.

1) Implicit activities as an inferential process

It is common to hear in an ordinary conversation "its implicit" meaning, "it was clear to me to make this implicit assumption to understand what's you means".

Scientific litterature ha been very prolific on this topic. Inferential theories of communication, pragmatics, ethnomethodology are some good examples where reseachers tried to develop approaches on how to use context in order to produce good inferences in order to interpret a message or a scene.

For exemple, Lewis (1969) defined two classes of methods for coordination. Explicit ones where the speaker explicitely express the information (like when he define verbally the address of an appointment) and implicit methodswhere it the hearer has to make inferences in at least three ways : salience (based on the most probable inference), precedence (based on whats happened before) and convention (based on a common practice or tradition).

This view of implicit activities based on an inferential process can be applied to non-verbal communication. We previously formalised this idea in the field of Air Trafic Control in order to understand the role of external artefacts (paper strips) and deictics (hand designation on radar screen) (Zorolla-Villareal, Pavard & Bastide, 1995; Salembier & Zouinar, 1999). A first attempt to assess the relative role of explicit and implicit activities has been made for ATC controlers (Bressolle, 2000).

From these studies, it appears clearly that non-verbal communications play a significant role because of its non-intrusive characteristics and because it reduces significantly the workload in order to elaborate mutual knowledge betweeen actors.

2) Implicit activity as an organisational process

Following this interpretation, implicit activities are defined by opposition to explicit ones (like those defined by organisational methods). It is a common practice in organisational theories to describe a task as made from a set of subtasks related by a control procedure. This practice is based on the very strong assumption that a task manager has a clear view of both task decomposition and optimal control procedures. Because of complexity in most cooperative environments, agents has to permanently adapt their frame of task organisation and control procedures and to produce alternative frames of working.

For example, in an medical emergency control center, it is explicit ly mentieonned that only doctors slould take medical decisions. Cooperative practices nevertheless push the group of agents to share medical decisions and it is a frequent practice to see phone operators to take medical decisions (under the control of doctors and with the implicit assumption that the phone operator shoud refer to the doctor in case of doubt).

We will be interested in these two kinds of implicit activities and we will describe the main implicit communication mechanisms for cooperation.

1.2 Implicit activities and cooperation

Implicit activities related to cooperation are most of the time related to the same mechanism: broaccasted communication, overhearing, overseing, action and communication through artefacts.

The most important mechanism for cooperation is related to the dual process: broadcasting – overhearing information.

For example, when a message is sent by speaker toward a particular hearer, it may also be received and interpreted by other persons (overhearers) depending of several factors:

- Presence or absence of overhearers
- Loudness, clearness of the speech act
- Overhearer's workload
- Quality of overhearers (allowed, not allowed, authorised, etc.)
- Communiation media

The efficiency of this mechanism depends of all these factors, which cannot be controled due to their opportunistic nature. Nevertheless, broadcasting is a key factor for cooperation because of its cognitive economy principle: it is almost at no cost that the speaker distribute its information in the environment; the broadcasting - overhearing is almost non intrusive because it do not force the overhearers to listen the broadcasted message and it is a regulation mechanism because only non busy overhearers capture the broadcasted information.

For all these reasons, braodcasting is a generic process in cooperative activities. It is also an implicit and non-deterministic process because the speaker cannot control exactly who got the information and how this information has been interpreted.

Broadcading has been described in the domain of verbal communication (Goffman, 1987, Kerbrat-Orrechioni, 1990). We will also stress the role of this mechanism when artefacts are used. Artefacts are also of importance when agents cooperate in a close and visual relationship. An agent may intent to communicate its intention, action moving an object in its environment and the same theoretical considerations may be taken in order to model the role of artefacts in cooperation.

We will also point out the role of postural communication as a broadcasting process. We will show how people express their communication availbility through various postures. These postures can be interpreted by other agents as indicator of when and how to interact (Pavard, Benchekroun & Salembier, 1990).

Finally, we will put forward the paradoxal argument that implicit activity, due to its non-deterministic dimension is the main contributor to robustness of complex cooperative systems.

2 CASE STUDIES

In order to clearly illustrate the role of implicit mechanims in cooperation, we will describe two wok situations wo have analysed in details (activity analysis through direct observation, video recording & debriefing).
The first one concerns the work of air trafic controlers in a situation where they use paper strips in order to manage the regulation of aircraft trajectories. We will show the cognitive role of paper strip artefacts in problem solving and cooperation.
The second one concerns the work done in an emergency control room where medics and phone operators have to manage external calls in order to send ambulances. This case will examplify the role of multimodal broadcasted communications (verbal, postural, artefacts) and also how non deterministic communications contribute to the robustness of cooepratuive systems.

2.1Air Trafic Control

The regulation of air traffic in France is made by two controleurs working in a close relationship. A radar controler is in charge of final decision (which route to give to aircrafts) and a radar assistant prepares the work for the radar controleur (checking incoming flights, overseeing the air trafic situation and helping the radar controleur depending of the situation). The working tools are presently relatively straight: a radar to visualiste aircraft trajectories, paper strips to materialise en-route aircrafts and communication devices to speak to pilots or other agents on the ground. Software tools are used only to detect unwanted situations like extreme proximity between two aircrafts (Fig. 1).

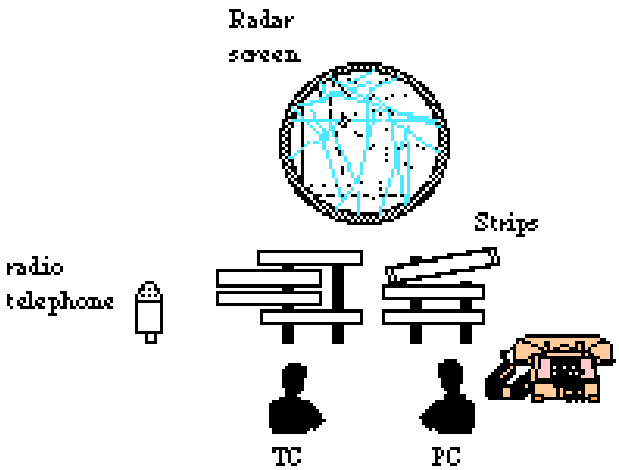

Fig. 1 **:** *The french airspace is configured into sectors which are areas of control responsibility. Each sector is normally controlled by a team consisting of two air traffic controllers (the radar controller TC;and the assistant controleur PC) whose objective is to direct flights safely and efficiently to their destinations: the role of the TC is to give instructions or information to pilots. The PC helps the TC by communicating with adjacent sectors for coordination and the transfer. Controllers have three main tools to achieve their tasks: strips which are strips of card arranged in racks in front of them, a radiotelephone enabling them to talk to pilots, a radar screen which represents the current state of the traffic (flights in the airspace,their position, etc.). This tool also provides information such as the level of aircraft, their speed, the flight number, etc. The telephone is principally used for communication with other sectors.*

Air Traffic control has been the topic of many studies showing how artefacts interact with individual or collective cognition (Bressolle, Pavard, & Leroux, 1995; Hutchins & Klausen, 1996). From these studies it is possible to show how artefacts structure cognitive activity in a non deterministic way.

The Figure 2 shows an example of how the radar controler organises informaly his paper strips during his work. Strips may be physically arranged from top to down depending of the altitude of aircrafts (each controller have its own strategy). Strips may also be grouped and moved to the right in relationship to their probability to be in conflict (see left part of Fig.2). It is interesting to see in this last case that the action of moving two strips can be interpreted by the assistant controler to notice the conflict detection by the radar controler. This is a classical case of communication through artefacts. We can notice its non-intrusive nature (the assistant controler do not have to make an explicit request to the radar controleur to see if it has detected the conflict). We can also see how non-deterministic is this communication because nothing confirms the success of this communication act. Nevertheless this inference (the radar controler detected the conflict materialised by the two strips) could be crucial for the rest of the task.

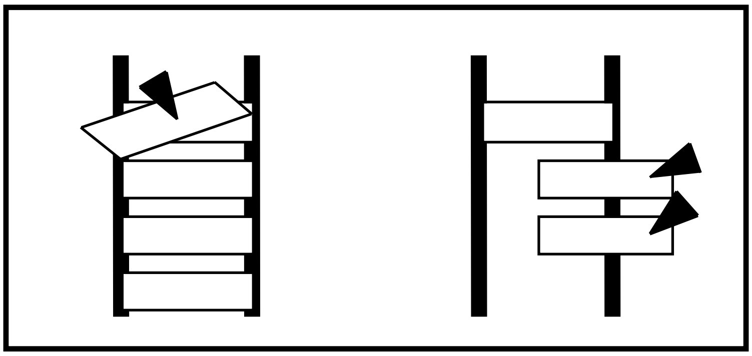

Fig. 2 *Paper strip organisation on the board of air traffic controlers. On the left, the assistant controler puts a strip in an unusual way to mention something special with the arcraft. On the right, the radar controler, moved to the right two strips in order to easely remenber he has to regulate the aircrafts materialised by the strips.*

Following such observations, it is possible to assess the relative importance of comunication through artefacts. In several studies, we used two methodologies. The first one is based on the analyse of "micro incidents". Micro incidents are small errors made by controlers but errors recovered by the analysis of contextual information (information previously broadcasted). Taking into account each micro incident and looking for which event has been necessary to recover it, it is possible to assess the relative role of verbal and non verbal communications (Bressolle, Decortis, Pavard & Salembier, 1996). We tried in this perspective to draw a systemic model of decision under uncertaincy taking into account explicit and implicit behaviours.

2.2Cooperation in an emergency control room (SAMU)

In this example, we will show how broadcasted verbal communication is used for cooperation and again its non-deterministic nature.

The control room is responsible for receiving emergency calls from and dispatching fire engines (which can also provide some paramedic assistance), sending ambulances, notifying the on-call doctor and giving medical advice over the phone.

From an initial call, the fireman or nurse must assess the nature of the incident and decide on the most appropriate course of action. This process often involves cooperation with other team members. For example, a nurse may ask for advice from the physician, and then make a request for a fire-engine to the fireman. A fireman may transfer the call to the medical team if the incident is serious, and report that a fire-engine has already been sent. Members of the medical team may communicate either directly (face to face), via artifacts (e.g. telephone or software), or non-verbally. All the members of the team must try to be aware of ongoing events.

Figure 3 briefly explains how the broadcasting mechanism operates on a control room.

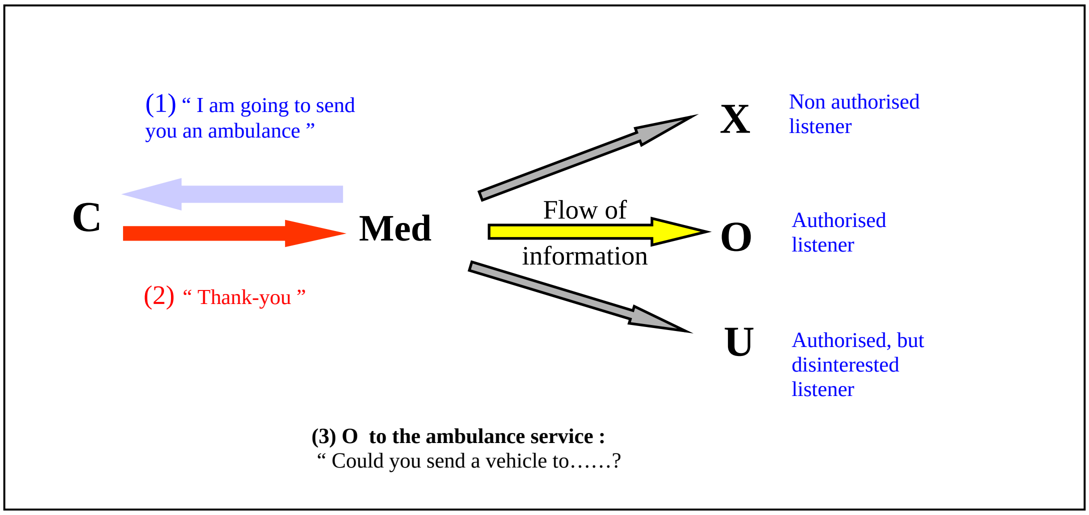

Fig. 3 An example of the broadcasting mechanism. A caller, C, telephones a medic (Med) at the emergency centre to request an ambulance. This communication can be overheard by several people depending on their geographical position and the volume of the communication. These people can be authorized, unauthorized, interested or disinterested interlocutors. The fluctuating status of the interlocutors, as well as their geographical positioning or their level of involvement with a task, will significantly influence the development of the common knowledge of the collective. In this example, we can see (in 3) that agent O overheard the conversation between the caller and the medic (1 and 2) because of his spatial proximity to the doctor and the volume of the communication. As a result, agent O dispatched an ambulance without the medic making an explicit request.

Broadcasting is probably one of the most important mechanisms for understanding the efficiency of a collective in situations of co-presence (real or virtual). Indeed, it is the only mechanism which allows information sharing at a low cognitive cost. The classical theories of communication (mainly dyadic) have seldom analysed its functional role (Decortis and Pavard, 94), although its cognitive components are described with precision (Goffman 87).

The cognitive dimensions of broadcasting are varied and each one contributes to making the process non-deterministic. Some of the main factors contributing to this mechanism are: the number of people present at the time of the communication act, their status (authorized or unauthorized interested, etc.), their availability and the context etc.

As previously mentioned, it is extremely difficult to trace the flow of information (c.f. the arrows in figure 3) associated with this type of communication. Neither the actors involved, nor the observer have the means or the cognitive resources to know who heard the message and even less to know how it was interpreted. In addition, it is often very difficult to separate the environmental factors from the internal factors.

2.3Implicit activities, broadcasted communications and flexibility

One of the most interesting properties of socio-technical systems is their capacity to reorganise rapidly their functional structure in response to an environment change. Depending on the context, agents can significantly modify the "rules of the game" and, for example, change their cooperative mechanisms. This change can occur without having been programmed at a central level. The example shown below illustrates this type of mechanism. It describes a cooperative episode between several agents working in the same room. The cooperative scenario is based on the broadcasting mechanism: a loudspeaker (held by a medic dressed in white in the photograph of figure 4) passes on the radio communications,

transmitted by ambulances at the scene of accidents, to the rest of the collective (the personnel of the emergency centre). We have seen that the broadcasting mechanism facilitates efficient cooperation. The same medic controls the volume of the loudspeaker, according to the ambient noise and the interest of the message to the collective.

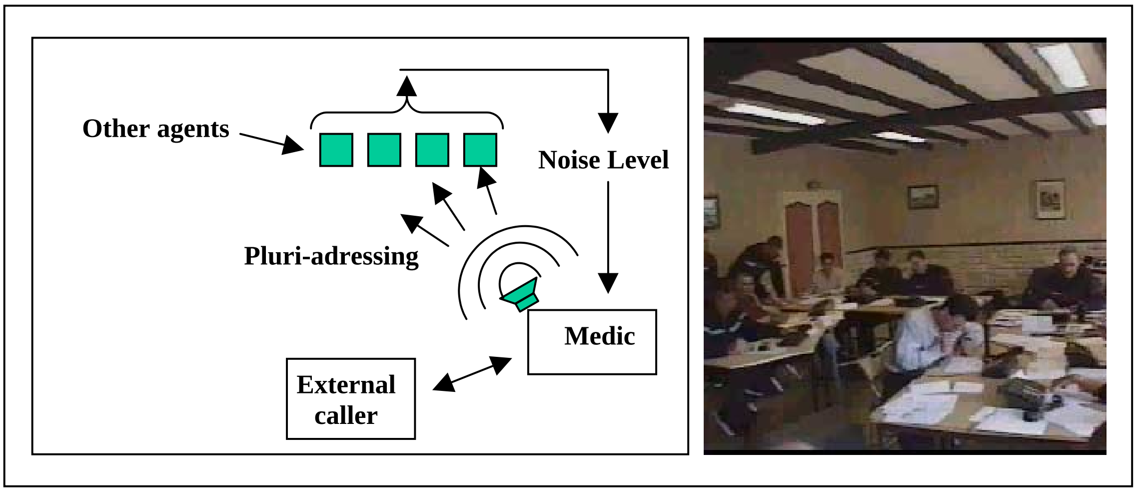

Fig. 4 An example showing the flexibility of structural properties of a communication system. The mode of transmission of information between the agents depends on environmental factors (e.g. ambient noise) and informal control exercised by individual agents. The medic (shown in white) changes the volume of the loudspeaker (and thyen the information flow) , depending on the semantic content of each message and the level of noise in the room. This allows him to adjust the scope of broadcasted message.

We can see from this example that the structural properties of a communication system (here, the mode of information distribution) depend on environmental factors (the operator regulates the loudspeaker volume according to the ambient noise) and a semantic analysis of the content of the message. According to the context, i.e. the estimated relevance of the message for the collective, the operator will increase or reduce the volume of the loudspeaker in order to optimise the way information is distributed to the collective.

This mode of communication control is neither centralised by any structure, nor formalised (there is no official or semi-official rule specifying the mode). The operator applies the mode of control probably without having specifically thought about its utility (the operators are not generally aware of the importance of broadcasting mechanisms to the collective and often think of it as a source of noise).

The example shows that the structure of the communication system, on which the efficiency of the collective depends, is subject to real time informal adjustment mechanisms. The communication function of the collective depends here on environmental constraints (ambient noise level) and contextual factors (the interest of the message to the collective) which are controlled by individual agents.

If this type of situation had been analysed according to the functionalist paradigm, the emphasis would have been on dyadic communications, such as the direct communication between agents and the telephone communications, etc. Peripheral mechanisms (such as broadcasting and the ambient noise) would have been treated as more or less disturbing secondary events. However, these mechanisms are essential if we are to understand the efficiency of the collective. In this type of complex situation, the functionalist approach, would underestimate the environmental factors and the non-deterministic interactions between the agents. The model would have been of little ecological relevance since it would not have allowed us to understand the processes of common knowledge elaboration which are related to broadcasting.

The functional importance of the broadcasting mechanisms using the tuning of the loudspeaker volume has been simulated by computer in order to show the importance of regulating communications at the level of the collective (Dugdale & Pavard, 2000).

2.4The distributed character of information and representations

The notion of distributed information conveys different concepts. In its most commonly accepted meaning, a system is said to be distributed when its resources are physically or virtually distributed on various sites. The concept of distribution supports the concept of redundancy, when some distributed resources are redundant.

The notion of distributed representation also exists in the field of cognitive psychology [Zhang and Norman 94, Hutchins 90, Hutchins 95]. It covers the fact that, in the interaction between an actor and his environment, artefacts (tools) play an important functional role in the organisation of the reasoning and the transmission of knowledge. To illustrate this principle, we could refer to the previous example of paper strips in the domain of air traffic control. Paper strips generate different kinds of representation depending of actors. Thus, we can speak about distributed representation, since some cognitive properties (such as memorizing and problem structuring etc.) are partially supported by artefacts in the environment. In one way, this notion is close to the concept of physically distributed systems.

Finally, we could introduce a third meaning to the notion of distributed systems, which stems from connectionist models and conveys essential concepts for understanding the robustness of the collective in processing data. In the connectionist meaning, a distributed system is one where it is not possible to localise physically the information since it is more or less uniformly distributed between all of the objects (or actors) in the system (Figure 5).

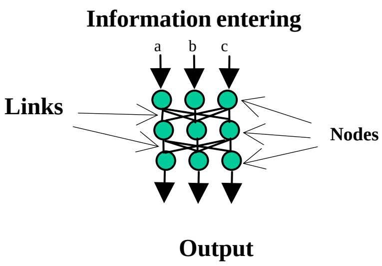

Fig. 5 *Diagram of a connectionist system (here a simple neural network). The information arriving in the system is distributed between a set of nodes (or neurons) as a function of the strength of each link. The strengths of the links are gradually adjusted using a learning mechanism, which compares the actual behaviour of the network with the desired behaviour.*

The learning mechanism ensures the distribution of the functional properties of the network (the property of recognition) between its neurons. If a network is forced to learn how to recognise shapes (or to associate actions with some conditions in the environment), the learning mechanism will distribute the information throughout all of the connections in the network. It will not be possible to attribute to any one of the connections a particular functional role. Such a network of distributed information offers some interesting characteristics of robustness and the ability to extrapolate answers to never seen situations. The term “distributed representation” is inappropriate here since it is impossible to identify any form of representation in such a network. The representation is “dissolved” either in the nodes of the system or in the links. Thus, a distributed system, in the connectionist sense, does not distinguish between concept, representation, and context, since these three entities are “encoded” simultaneously on the same support (nodes and links). We argue that a truly cooperative system works on both representational and connectionist modes. This is why the system is particularly robust in complex environments, which are unpredictable and non-deterministic.

The following example shows a situation encountered during our study of the emergency centre. The aim of the collective was to maximise cooperative behaviour between the actors, in order to respond in the best possible way to events in the environment (such as unexpected calls and work peaks, etc.). We have shown the efficiency of this type of collective activity is based on a situation o6

co-presence, which allows information to be distributed, by broadcasting and overhearing. Figure 5 represents this type of information distribution between agents and shows the importance of the interaction between the environmental factors (e.g. noise level and space constraints) and more central processes (such as the control of the modes of communication).

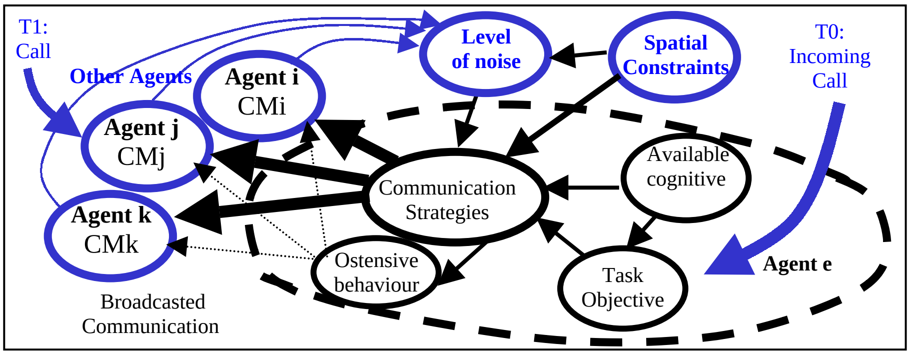

Fig. 6: *A diagram showing the distributed nature (in the connectionist sense) of cooperative systems. The diagram represents a collective composed of several agents (shown by circles: Agent i, j, k, etc.). At time T0, an incoming call is dealt with by agent e who adopts a communication strategy which aims to control the distributed character of the message. Verbal information (shown by thick black arrows) is distributed in a non-deterministic way (by broadcasting) to the other agents (Agents i, j, k) according to the characteristics of the environment: the noise level, the spatial constraints (the distance between the agents), the cognitive resources (workload) and other factors such as postural or gestural ostensive behaviour (shown by dotted arrows) which allows agents to control their listening behaviour [Benchekroun 94]. If at time T1, a call arrives which is related to a previous call, but is taken by an agent other than agent e, the collective (i.e. one of the other agents in the room) will be able to handle the call because of the common memory (CMi, CMj and CMk) established by the broadcasting mechanism.*

We can see that a collective in a situation of co-presence, possesses characteristics which are comparable with those of a connectionist system. The information is distributed between the actors, with some redundancy, due to the broadcasting mechanism. Such a system can be regarded as complex because part of its functions cannot be reduced to a representation where it is possible to locate precisely a relevant piece of information. Neither the actors nor the observer can, at a given moment, give a deterministic plan of this process.

3 WHICH CONCEPT TO MODEL IMPLICIT ACTIVITIES?

Following these examples, implicit activities are difficult to model and take into account for the design of cooperative systems. Two philosophical approaches can be taken to investigate the problem. The first one, which could be called positivist[1] and who would state that the non deterministic nature of broadcasted communication (either verbal and non verbal, mediated or non mediated by artefacts) is only due to our lack of knowledge about inferences made by subjects. The second position "post modern"[2] would abandon the idea of being able to render explicit communication even if we spend all the time necessary to understand the cognitive situation. Several strong arguments may be put forward in this direction:

- Human communication is untractable due to the broadcasting mechanism (see 2.2).
- Non determinism is not a terrible sickness but contrarily a necessity in order to insure robustness in complex systems (see 2.3 & 2.4).

[1] in reference to the positivist school of physics that never accepted the real non deterministic nature of quantum mechanics but accepted it "waiting" for better time where we would have more knowledge in causality

[2] in reference to the post modern movement (Derrida, Cilliers, etc..) which state that the meaning of words cannot be automatically computed but results from situated interactions always different.

- All complex socio technical systems are non deterministic dure to their non linear regulation loops.

If we accept this argumentation, it has some strong methodological consequences for the enginnering process.

First of all it implies to accept to live with the two sides of the engineering reality: the deterministic side (which is usually useful in nominal modes of working, in stable environments, etc..) and the non deterministic side made of non controlable processes. Control strategies are not working in the same way in both cases. In stable environments, the control can be classic and is well known by organisation. In unstable or complex environments control cannot be applied on a deterministic way, but applied only by constraints that limit the domain of decision without strong specification on how decisions are made.
Following this idea it would be necessary to abandon the idea of looking for zero fault systems because these systems can exists only on utopic worlds where the controler (manager) is enough aware of all change in the environment. Models should be much more sophisticated, taking into account the flexibility of the process instead of its performance or productivity by itself. For example, the designer will be more interested in how the communication system may generates mutual knowledge in several situations rather than how to solve the problem thus trusting the capabilities of the group to self organise its activity in unexpected situations. In the same time, it woiuld be necessary to design tools that help agents to get the good information with anminimaly effort. The designer is thus driven to think more in terms of how to improve the communication system for a better cooperation than how to solve the problem itself.

Secondly, from a methodological point of view, engineering cooperative systems cannot be driven only by technical consideration or even external analysis. It is necessary to investigate the cognitive processes at low level in order to grasp the content of implicit activities, which are responsible of the robustness of the system.

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Human Factors Issues for Future Command

Dr. Peter Essens*
TNO Human Factors
PO Box 23
3769 ZG Soesterberg, The Netherlands

SUMMARY

Based on close interactions with military decision makers and strategic research studies critical issues in future command are identified and placed in a model of six command themes.

INTRODUCTION

It is almost commonplace to say that military operations have become more complex. What exactly has become or is becoming more complex; and is this different from say 15 years ago? We see two major, but different sources of complexity: the development of higher operational tempo and the increased number of operations other than war. Higher operational tempo refers to the quickening of the command cycle, in order to outmanoeuvre the opponent.

In 'traditional' warfare specific time frames were accepted in the successive top-down planning and implementation of orders, based on the idea that the opponent party was in general symmetric to own forces. Now, with the occurrence of asymmetric parties, response should be fast and flexible.

Military strategists seek to reduce top-down command cycle timing. US Brig.Gen. Alexander stressed the importance of augmented visualisation of the battlefield and quicker sharing of this picture up and down (Alexander, 2000).

Roles and autonomy may change, which can go either way: more centrally directed and controlled, or more decentralised with augmented authority at lower levels of command. It is expected that less time will be available for human information processing and decision making processes, while at the same time there is more information to process. This leads to a requirement of improved perception and direct understanding of the relevant cues in tactical information.

Another source of complexity is the change in types of operations, in particular in peace support operations.
- In these kind of operations military activities are strongly restrained by rules of engagement, direct interaction with the civil population, uncertainty and unexpected dangers, and isolated operations.
- Decision making trade-offs are often complicated by unclear rules and politically sensitive choices.
- International cooperation between different militaries and with non-governmental organisations, and confrontations with unpredictable 'civil' opponents, put high responsibilities at lower levels of command (McCann & Pigeau, 2000; Essens, et al., in press).

These kind of operations, which for some armies make up most of current operations, require additional to the standard military combat skills specially developed qualities and skills of commanders and soldiers.
Additionally, team behaviours and social qualities are important, such as concern and personal interest, social support and trust. Selection and training to develop these individual and team behaviours is a requirement that is essential to these operations.

The complexities described above provide new challenges for human factors research.
It should be noted that the challenges arising from an increase in operational tempo are more well-defined than command in peace support conditions.

* Dr Peter Essens is working in the area of naval and army command and control, in particular team design and design of flexible task organisations. He also specialised in civil control and reporting centres. (For more information: essens@tm.tno.nl).
Sections of this paper were based on contributions by colleague experts at TNO Human Factors.

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One reason for this is that operational tempo requirements are interpreted along traditional lines of command and control, this is: new tools for essentially the same operational activities. However, peace support operations require more attention to particular behaviours, such as leadership and team behaviours, which had been less in operational and scientific focus in the cold war scenario's.
The complexities of peace support operation are discussed in length in the forthcoming book on experiences and research on peace support operations (Essens, at al., in press).

I will focus here on challenges related to command and control and, following the aim of this specialist meeting, I will present a list of challenges for several areas of research, based on new research developments at our human factors institute provided to me by my colleague human factors experts. The question to them was what issue in your area of expertise will be most prominent for the military in the 21st century, say the coming 5-10 years.

HUMAN FACTORS CHALLENGES

Command and control processes can conveniently be organised along the information processing loop of observe, orient, decide and act (OODA). In figure 1 a modern variant of this well-known information loop is shown as a basis for representing critical issues for future command. Two other elements are added to the information cycle: the coordination and cooperation team task needed to perform complex tasks that are distributed over team members, and the environmental factors that affect human performance. (Training, as a distinctive issue, is here covered in each element).

This (non-exhaustive) set of elements represents central activities and conditions in command and control that are affected by the requirements of operational tempo. Of each element, one topic is shown which represents one opportunity for improving human performance and command and control.

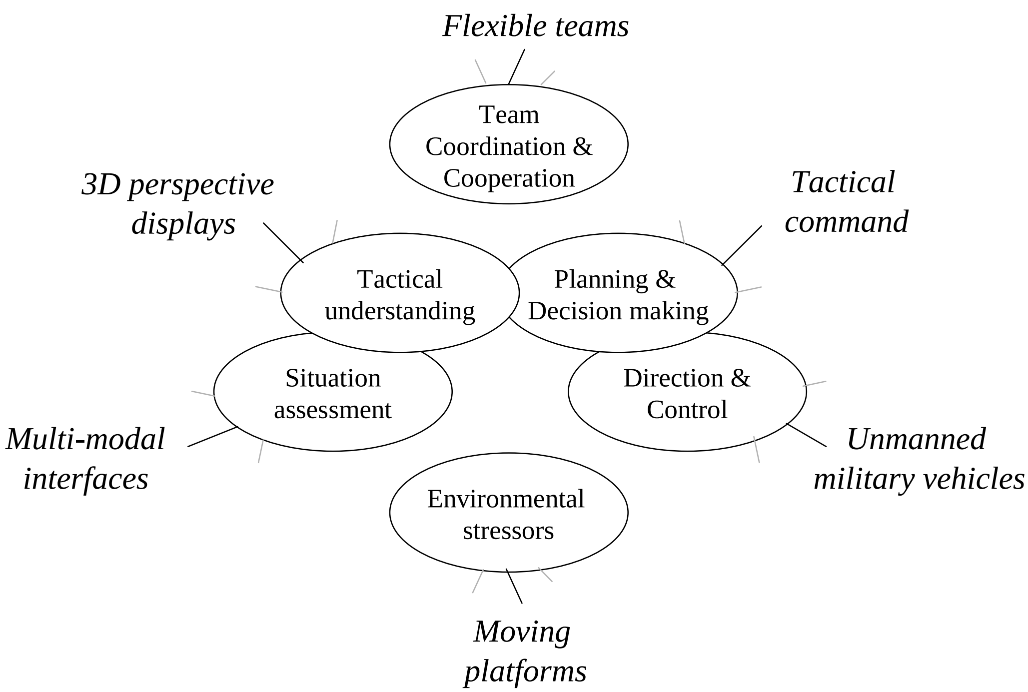

Figure 1. Command and control elements and selected human factors focal points.

Multi-modal interfaces[1]

An important aim of multi-modal interfaces is to maximise human information uptake. Effective visual and auditory information presentation means that information is prepared using the capacities of the human's sensory and mental capabilities such that humans can easily process the information. New interface technologies are being developed that seek to optimise the distribution of information over different modalities:

- image fusion - real-time sensor images (CCD, thermal, II, SAR, Ladar, etc); stored images; geographic images (maps)
- new display technologies - 3D stereoscopic displays; head-mounted displays other 'body-mounted' displays; 3D auditory "displays"; high quality virtual environments
- automated pre-selection and decision support - speech recognition; automated target detection.

A problem in this context is the control of information overload. Or, how can overall workload be used to redirect the distribution and presentation of information. If workload is high, information presentation should not add to this. Another, relatively new, problem is that due to reduced influx of military personnel, people with mild defects (colour defectiveness, spectacles, mild hearing loss, mild binocular vision disorders, etc.) should not be excluded anymore. To compensate for these defects specific requirements should be formulated for new technologies.

3-D perspective displays[2]

A central aim of 3-D perspective displays is to represent multiple information elements such that these are directly perceived in relation to each other. It is expected that situational awareness will increase, and, in combination with tactical relevant information, the tactical understanding of the situation will be improved. There will be no time loss from switching between multiple representations. Also loss of 'visual momentum' can be avoided and a continuous and rich mental picture related to the tactical situation is continuously being maintained and updated. The challenge will be to identify those cues that determine the essential tactical meaning of the operational space and represent these in an integral picture that can be readily understood and transformed into tactical decisions.

Inherent in the perspective view is that objects are presented larger or smaller as a function of the operators viewing distance, location and angle. Objects "close" to the operator will be shown with much more resolution than objects at larger viewing distances. In many cases these differences will not necessarily reflect differences in tactical relevance and meaning. One can question how accurate the different information elements can be perceived. To prevent errors and to facilitate appreciation of tactical information, additional projections and visual cues may prove to be necessary. Furthermore, to resolve ambiguities and to reduce clutter, operators should have full control of viewing distance, angle and position. Although this will give the operator the flexibility to visualise tactical data more freely, it is still not fully understood what effect frequent changes in view will have on spatial orientation and situational awareness.

Tactical command training[3]

Commanders need to select and process vast quantities of information to assess the true nature of often complex situations, and to make decisions under time pressure that may have major tactical or political consequences. The increased role of lower command levels in peace support operations has created a problem of timely development of commanders skills required for these tasks. In the past, skills could grow when going through the successive command levels before being required to make complex command decisions. Now, according to some, young commanders are confronted with difficult command decisions too early in their career.

The research challenge is to bring young commanders up to the right skill level. This should cover both tactical skills and social skills. For tactical skills (the focus here), scenario-based training is generally considered an appropriate approach for acquiring these competencies. Although scenario-based training is

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[1] Information provided by Dr. Frank Kooi (kooi@tm.tno.nl)

[2] Information provided by Dr. Peter Passenier (passenier@tm.tno.nl)

[3] Information provided by Dr. Karel van den Bosch (vandenbosch@tm.tno.nl)

more and more used for training tactical command, there exist, however, a number of fallacies, problems, and challenges that need to be solved for successful practical application. I will list here some of the training issues that have to be resolved:

- Event specification and scenario design. Scenarios must be constructed in such a way that trainees expand their domain knowledge, learn to recognise and assess prototypical situations, and practice the application of domain knowledge to novel situations. Research is needed to determine how (a series of) exercises should be selected and designed to ensure that they systemically call upon all the knowledge and skills formulated in the training objectives.
- Performance measurement. Assessing trainee performance in tactical command is not straightforward because critical skills (e.g., reasoning, memory retrieval, and knowledge integration) can not be directly inferred from observable actions. Research is needed how to define performance measures that allow assessment of whether learning objectives are achieved, and that enables determining why performance occurred as observed and diagnosis of knowledge gaps or misconceptions.
- Performance diagnosis. The observation that experts often have difficulty making their assessment principles explicit makes SMEs (Subject Matter Experts) not by definition good OTs (Observer/Trainers). SMEs need supportive technology and training how to attach clues to the assessment for providing feedback. Methods for training are needed that enable SMEs to diagnose trainee performance by reconstructing it in terms of preceding, or anticipated, events that resulted in that behaviour (train the trainers!).
- Feedback and debrief. In the development of a novice to expert level there is ideally a shift from external control and evaluation to self control and evaluation, reduced scaffolding and collaborative assessment techniques. Recent views on debrief argue that the nature of After Action Review should be tuned to the particular stage of skill development. Research is needed to develop flexible and adjustable models of brief and debrief.
- Agent-based team training. Tactical command is often performed in command teams. Team tasks require the utilisation of cues that originate from team environments. For learning the relevance of these cues, and learning to respond appropriately, teams consisting of *trainees* are not very effective environments, because they do not generate the right cues yet. The use of simulated team members may provide a more controlled and transparent learning situation. Research is needed to specify the demands on effective agent-based scenario-based team training.

Unmanned military vehicles[4]

Although unmanned military vehicles (UMV's) exist already for some time, the political requirement for minimal chance of losses and the military requirement for lower attrition rates has given a new push to further development and application. Nowadays these systems typically support command and control purposes, in particular situation awareness - hardware agents that provide virtual presence. But they will be used for logistics & transportation, weapon delivery, mine hunting, and more. Expectations are that unmanned/uninhabited aerial, ground, and naval military vehicles will become closely integrated into new concepts of operations.

The central HF issue is: how well can the operators of remotely controlled vehicles control and direct these, how well can one operator control multiple units and what support is required to boost performance. Some of the human factors issues associated with operating unmanned military vehicles have relevance across a large number of these vehicles and seem worthwhile to be studied in a broader context.

One problem for remote operators is appropriate situation awareness. This counts for static environments, but when the operator is also on a moving platform, or has to control multiple vehicles at once, the situation becomes even more complex. Experience with controlling multiple drones moving around a minesweeper has shown that even a simple port-starboard distinction is being mixed up when the vehicle's orientation is the opposite of own orientation. More complex scenario's are: controlling one or more Unmanned Combat Aerial Vehicles from a future JSF (Joint Strike Fighter), or coordinating between multiple operators and vehicles. What are the limits and how far one can go with support? These issues are under development.

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[4] Information provided by Dr. Hendrik-Jan van Veen (vanveen@tm.tno.nl)

A second HF problem concerns the psychological aspects of controlling remote machines. It is expected that operators develop higher risk-tolerance for operations with unmanned vehicles than when physically present. Decisions made at a distance (e.g., to fire a weapon) may be less carefully made. How will uncertainty on data latency and fidelity affect decision making? And if these are serious problems, what interfaces can help to overcome these problems?

At least three major developments can be identified which will influence the UMV-related HF research agenda now and in the near future:

- Increasing deployment of UMV's (scale aspect), leading to issues such as: interoperability (e.g., supporting joint/combined operations down to the control station level) and integration of UMV's in the C2 process (e.g., campaign planning, tasking, etc.).
- Increasingly advanced unmanned platforms and complex missions lead to issues such as: manned/unmanned collaborations (e.g., in air strike operations); control station complexity (e.g., dynamic/adaptive ratio operators-platforms, distributed control stations, etc.).
- Technological developments enable increasing amounts of automation. This leads to issues such as: UMV operator selection and training; a shift from manual control to the operator as a supervisor.

Moving platforms[5]

In all operational conditions where crew is operating in a moving environment (from frigate to tank to moving base simulators), task performance can deteriorate due to motion sickness and spatial disorientation. New developments such as super-agile aircraft and reconnaissance on the move, push the limits of the human vestibular system and, as a consequence, spatial disorientation may result in human failure to operate. Also in naval environments ship movements can reduce effectiveness of the crew. With the increased dependency on maximal contribution of all team members in a reduced team, knowledge about the relation between task performance and platform motions can be used to design less sensitive systems in reducing those motions or behaviours that are most provocative.

The human factors challenge is to effectively incorporate the existing body of knowledge in the design of systems, workspace layout, operational procedures, planning of missions and routes, and in the awareness of operational people.

Flexible teams

A flexible team is a team which is able to adapt to the circumstances and still remain effective in achieving its goals. The need for more flexible teams comes from the notion that missions and circumstances will become less predictable and will present more novel problems. The team should be able to address these problems by themselves, because often back up help is not readily available.

In Naval studies we found that current command centre teams have problems in handling workload peaks. Analysis of the distribution of workload over team members showed that some were systematically more loaded than others. These teams on board are usually composed of domain-specific specialised team members. Specialisation is partly required because of the complexity of the technical systems. This prevents team members from taking over or supporting tasks in other domains. With the requirement to reduce personnel, specialists should develop broader qualifications to help out in other tasks when required.

Flexibility is a requirement when team size is reduced. The challenge is to arrange a work organisation and a distribution of expertise over team members that allows the team to respond adequately. Besides work organisation and generalist-specialist distribution, information processes must be arranged such that all team members maintain a shared mental model of each others role and state of work. It has been shown that well-performing teams have better knowledge of each others roles and current state of work of each member than ill-performing teams.

Modern theories on team effectiveness, such as sociotechnical organisation design, argue that efficiency in an organisation or team is realised by clear arrangements of tasks and information feedback, but that the clustering of tasks into meaningful and responsibility clusters with social cooperation will unleash the ability and capacities of people and motivate them to put effort into their work. To further shape this: leadership, social support, and trust have strong motivating effects and help to cope with

[5] Information provided by Dr. Jelte Bos (bos@tm.tno.nl)

difficult situations. Flexibility requires a well-developed positive social structure in a team.

The human factors problem is how to get all these factors combined and balanced. Our knowledge of the interactions of these factors is still embryonic, but growing. The research agenda for this topic is to model team factors concerning task-oriented coordination and social-oriented cooperation. Main question is how team factors should be modelled and combined with task models.

Summary

We have selected six human factors issues that we consider to be pertinent for effective military operations for the coming 5-10 years. Information handling and processing is one crucial aspect of military operations. The major challenge will be to bring the wide range and high volume of data - military, civil, political - to the level of meaningful direct perceivable decision-level information. Unmanned vehicles provide a challenge to cognitively realise direct control over multiple platforms. Working in and on moving platforms has been an issue but can be solved now if available knowledge is included in the design of platforms and ways of operation. Effective and fast training for young commanders to give them the experience required to deal with the complexities of the modern operational field is an urgent challenge for human factors.

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Another Management :
Management by the Finalities

Prof . Dr Henri EGEA
Ecole des Mines de Nantes (EMN)
42, rue de Suresnes
92380 Garches
France

Abstract-- Reliancy thinking represents a shift away from the simplifying, reductionist approach that has traditionally shaped scientific enquiry. With the "ovoid attractor", we can represent Meta-models in the paradigm of complexity.

Index terms—reliancy thinking, , human scheduling

A. ABOUT THE PRINCIPLES AND THE THEORIES

I. INTRODUCTION

Until the mid-twentieth century, most sciences based their method on specialization and abstraction, i.e. reducing knowledge of a whole to knowledge of its constituent parts (as though the organization of a whole did not generate new properties in relation to those of its separate parts). Their key concept was determinism, in other words the denial of random factors and new factors and the application of the mechanical logic of artificial machines to the problems of living beings and social life.

Knowledge must make use of abstraction, but it must also be constructed by reference to context and hence must mobilize what the enquirer knows about the world. Individual facts can only be fully understood by those who maintain and cultivate their general intelligence and mobilize their overall knowledge. Admittedly, it is impossible to know everything about the world or to grasp its many and varied transformations. But no matter how difficult this may be, an attempt must be made to understand the key problems of the world, for otherwise we would be cognitive idiots. This is particularly true today because the context of all political, economic, anthropological and ecological knowledge has become global. As a result of globalization, everything must be situated in the planetary context. Knowledge of the world as such is necessary both for intellectual satisfaction and for life itself. Every citizen faces the problem of gaining access to information about the world, and then of piecing it together and organizing it. To do this, a new form of thinking is needed.

In the first place, the kind of thinking that separates must be supplemented with a kind of thinking that makes connections. *Complexus* means "that which is woven together". Reliant thought is a kind of thought that unites distinction with conjunction. Secondly, it is necessary to come to grips with uncertainty. The dogma of universal determinism has collapsed. The universe is not subject to the absolute sovereignty of order; it is the outcome of a "dialogical" relationship (a relationship that is both antagonistic, concurrent and complementary) between order, disorder and organization.
Reliancy thus connects (contextualizes and globalizes) and also comes to grips with the challenge of uncertainty.
How does it do this?

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held in Paris, France, 11-13 June 2001, and published in RTO-MP-077.

II. SCIENTIFIC CONTEXT OF THE RELIANT THOUGHT :

THEORIES AND APPLICATIONS

A. Information theory

Information theory gives access to a universe where there are both order (redundancy) and disorder (noise) and derives something new from it, i.e. information itself, which then becomes the organizing (programming) instrument of a cybernetic machine. For example, information that announces the sudden death of a tyrant introduces an unexpected new element into a situation.

B. Cybernetics

Cybernetics is a theory of self-controlling machines. The idea of feedback, introduced by the U.S. mathematician Norbert Wiener, breaks with the idea of linear causality and introduces that of the causal loop. The cause acts on the effect and the effect on the cause, as in a heating system where a thermostat controls the operation of a boiler. This regulatory mechanism makes the system autonomous, in the case ensuring that an apartment has thermic autonomy from the colder temperature outside. The feed-back loop may act as an amplifying mechanism, e.g. in a situation where an armed conflict reaches a critical stage. The violence of one adversary triggers off a violent reaction which in turn triggers off another, even more violent reaction. Very many instances of this sort of inflationary or stabilizing feedback can be found in economic, social, political or psychological phenomena.

C. Systems theory

Systems theory provides the basis of a way of thinking about organization. The first lesson of systems analysis is that "the whole is more than the sum of its parts". This means that properties emerge from the organization of a whole and may have a retroactive effect on the parts. For instance, water is an emergent property of the hydrogen and oxygen of which it is composed. The whole is also less than the sum of its parts, since the parts may have properties that are inhibited by the organization of the whole.

D. Self-organization

In addition to these three theories are a number of conceptual developments related to the idea of self-organization. Four names that must be mentioned in this context are those of John von Neumann, Heinz von Foerster, Henri Atlan and Ilya Prigogine.

In this theory of automata, von Neumann considered the difference between artificial automata and "living machines". He pointed to the paradox whereby the components of artificial machines, although very well designed and engineered, deteriorate as soon as the machine to operate. Living machines, on the other hand, are made of extremely unreliable components, such as proteins, which are constantly subject to deterioration. However, these machines have the unusual property of being able to develop and reproduce themselves; they regenerate themselves through replacing damaged molecules by new molecules, and dead cells by new cells. An artificial machine cannot repair itself, whereas a living machine constantly regenerates when its cells die. It is, as Heraclitus put it, "life from death and death from life".

Von Foerster's contribution is his discover of the principle of "order from noise". If a box containing a haphazardly arranged collection of cubes, each magnetized on two faces, is shaken, the cubes spontaneously form themselves into a coherent whole. A principle of order (magnetization) plus disordered energy have created an ordered organization. In this way, order is created from disorder.

Henri Atlan has developed the theory of "random organization". At the birth of the universe there was an order/disorder/organization dialogic triggered off by calorific turbulence (disorder), in which, under certain conditions (random encounters) organizing principles made possible the creation of nuclei, atoms, galaxies and stars. This dialogic recurred when life emerged via encounters between macro-molecules within a kind of self-productive loop which eventually became a living self-organization. The dialogic between order, disorder and organization exists in a wide variety of forms, and via countless feedback processes is constantly an action in the physical, biological and human worlds.

Prigogine introduced the idea of self-organization from disorder in a different way. In so-called Rayleigh-Bénard convection cells, coherent structures are formed and staid between two temperature levels when a thin layer of silicone oil is carefully heated. In order to be sustainable, these structures need supplies of energy which they consume and dissipate. Living beings have sufficient autonomy to draw energy from their environment and even extract information from it and absorb its organization. I have called this process auto-eco-organization.

The study of complex phenomena can thus be seen as a building with several floors. The ground floor consist of the three theories (information, cybernetics and systems) and contains the tools needed to develop a theory of organization. On the second floor are the ideas of von Neumann, von Foerster, Atlan and Prigogine on self-organization. I have added some other features to the building, notably the dialogical principle, the recursion principle and the hologrammatic principle.

III. RELIANT THOUGHT : THE THREE BASIC PRINCIPLES

A. The dialogical principle

The dialogical principle brings together two antagonistic principles or notions which on the face of things should repel one another but are in fact indissociable and essential for understanding a single reality. The physicist Niels Bohr believed that physical particles should be regarded as both corpuscles and waves. Blaise Pascal said that "the opposite of the truth is not an error but a contrary truth." Bohr put this in the following terms : "The opposite of a trivial truth is a stupid error, but the opposite of a profound truth is always another profound truth". The problem is that of combining antagonistic notions in order to envisage the organizational and creative processes in the complex world of human life and history.

B. The principle of organizational recursion

The principle of organizational recursion goes further than the feedback principle ; it goes beyond the idea of regulation to that of self-production and self-organization. It is a generating loop in which products and effects themselves produce and cause what produces them. Thus we, as individuals, are the products of an age-old system of reproduction, but this system can reproduce itself only if we ourselves become its producers by procreating. Individual human beings produce society in and through their interactions, but society, as an emerging whole, produces the humanity of individuals by conferring language and culture on them.

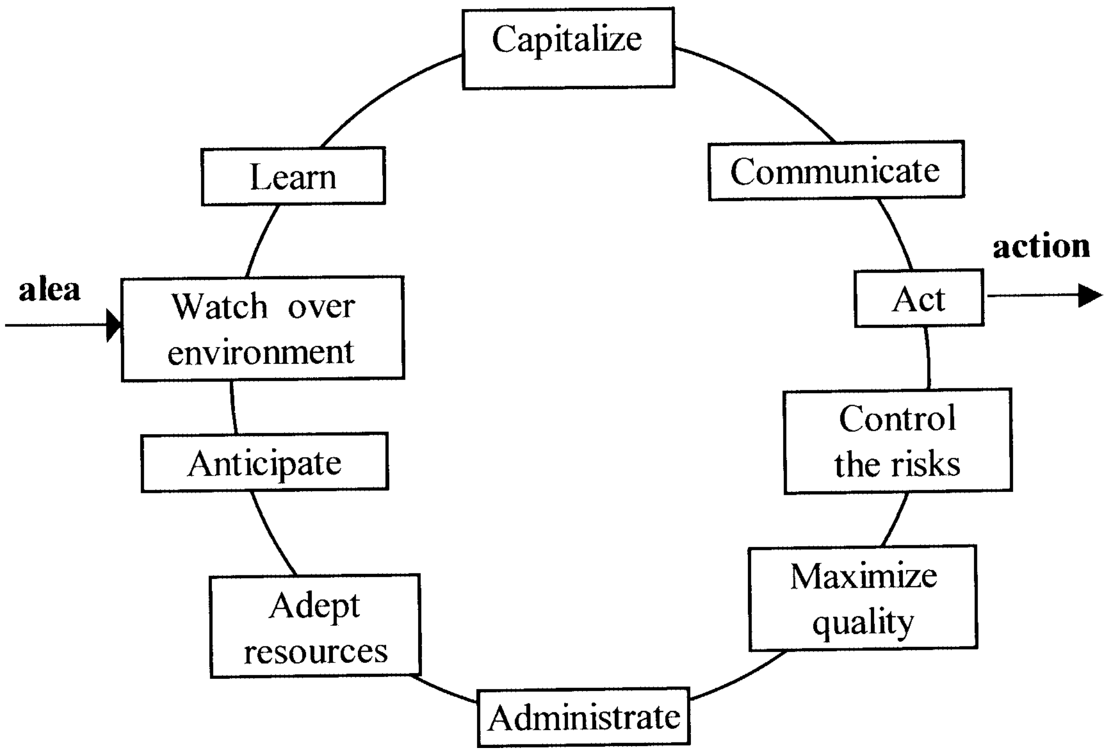
C. The "hologrammatic" principle

The "hologrammatic" principle highlights the apparent paradox of certain systems where not only is the part present in the whole, but the whole is present in the part : the totality of the genetic heritage is present in each individual cell. In the same way, the individual is part of society but society is present in every individual, through his or her language, culture and standards.

B. FROM COMPLEXITY TO META-MODELS

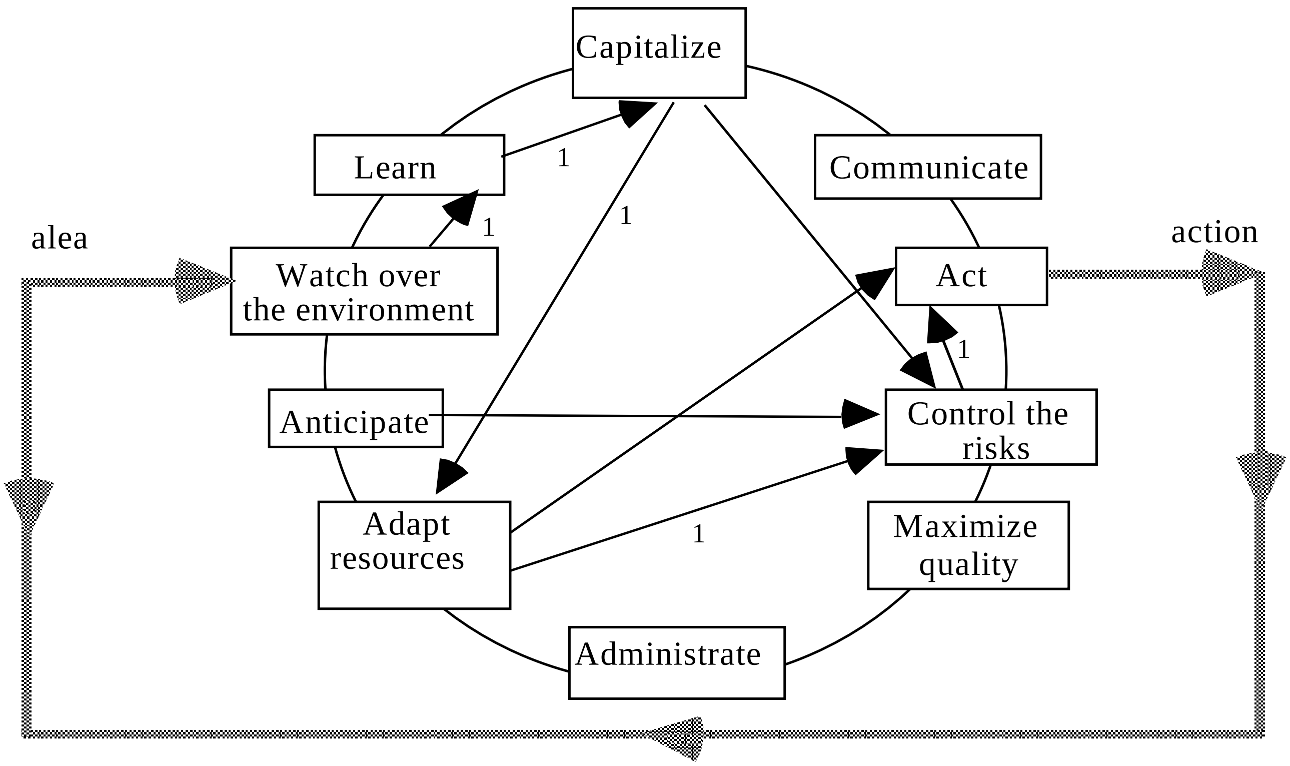
This part uses the theories previously described in this paper. It introduces the "ovoïd attractor" which consists of ten verbs in a paradigm connected to complexity.

The circular paradigm



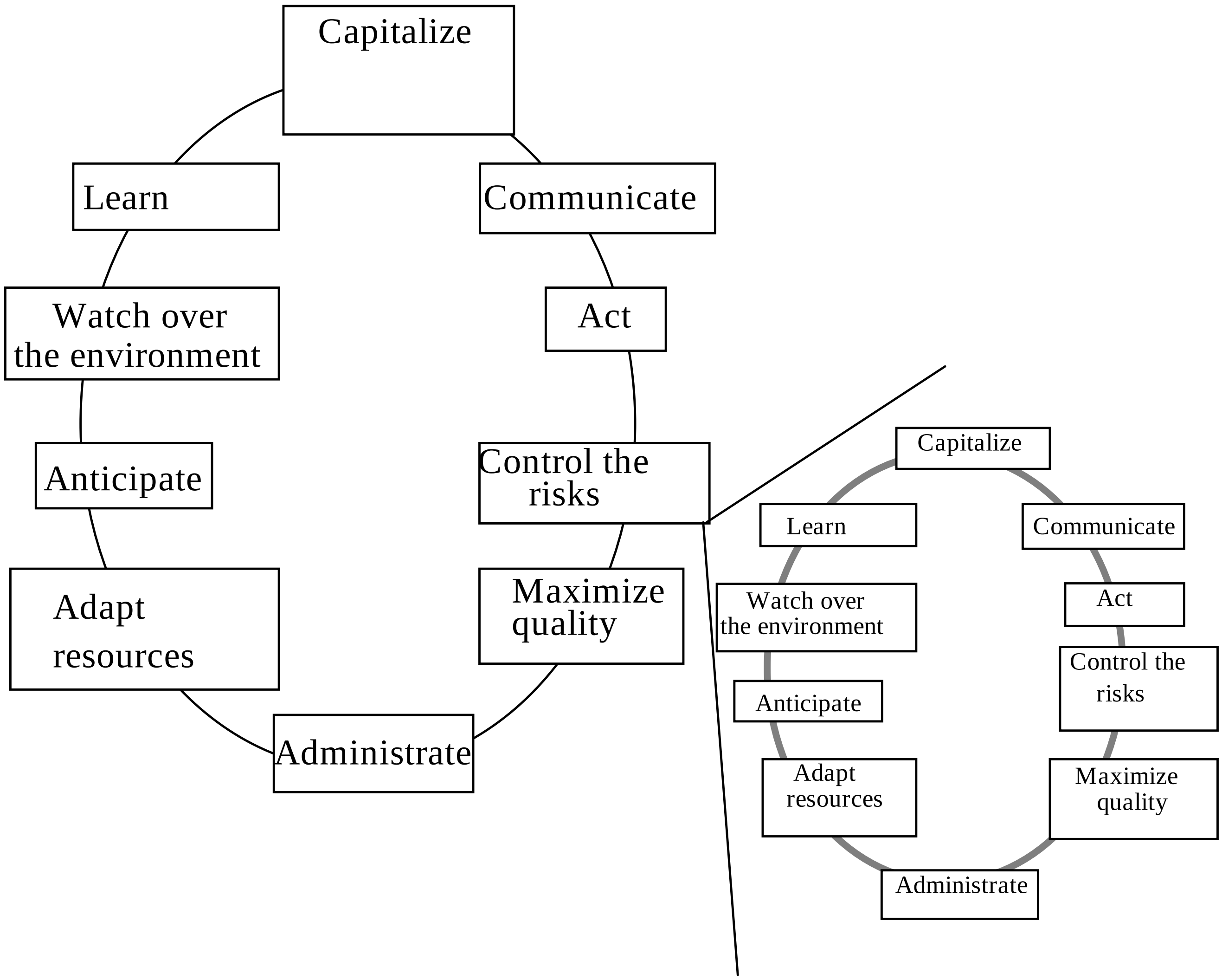
Similarity with a cell functionning

The behaviors of adaptation



Recursion, Dialogical and Hologrammatical principles in a complexity paradigm.

Representation of behavior activities with a fractality coherence



HOLOGRAMMATIC WAY FOR "CONTROL THE RISKS" ACTIVITY

CONCLUSION

Thinking in terms of reliancy is clearly not a mode of thought that replaces certainly with uncertainty, separation with inseparability, and logic with all kinds of special exceptions. On the contrary, it involves a constant toing and froing between certainty and uncertainty, between the elementary and the global, between separable and the inseparable. The aim is not to abandon the principles of classical science - order, separability and logic - but to absorb them into a broader and richer scheme of things. The aim is not to set a vacuous all-purpose holism against systematic reductionism, but to attach the concreteness of the parts to the totality. Linkage must be made between the principles of order and disorder, separation and connection, autonomy and dependence, which are at one and the same time complimentary, concurrent and antagonistic.

In short, reliant thought is not the opposite of simplifying thought ; it incorporates simplifying thought. As Hegel might have put it, it unites simplicity and complexity and ultimately reveals its own simplicity. In fact, the paradigm of reliancy can be described just as simply as that of simplicity. Whereas the latter requires us to dissociate and reduce, the paradigm of reliancy requires us to connect as well as to distinguish.

Reliant thought is essentially thought which incorporates uncertainty and is capable of conceiving organization. It is capable of linking, contextualizing and globalizing but can at the same time acknowledge what is singular and concrete.

La conception d'automatismes et les systèmes tolérants aux erreurs
Automation Design and Error Tolerant Systems

R. AMALBERTI
IMASSA, Département Sciences Cognitives
BP73, 91223, BRETIGNY-sur-ORGE, FRANCE

1. RESUME

La multiplication des automatismes est un trait caractéristique des vingt dernières années dans l'aéronautique, mais le bilan reste mitigé entre une performance accrue et un bénéfice réduit pour la sécurité. Cet article présente un bilan historique de l'automatisation des aéronefs, tant civils que militaires, puis explique les difficultés rencontrées par l'opérateur qui se trouve comme dopé par l'aide en même temps qu'il se retrouve en compétition au fur et à mesure que celle-ci devient plus intelligente et autonome. Les concepts de transparence, de compréhension, de confiance et de responsabilités sont au centre des critiques. La troisième partie de l'article indique des solutions pour une meilleure conception des automatismes qui puissent accepter le fonctionnement naturel, écologique de l'opérateur humain, et respecter ses objectifs, et ses apparentes approximations que l'on qualifie souvent à tort d'erreurs.

2. LA DÉFINITION DU CONCEPT D'AUTOMATISATION ET SON HISTOIRE RÉCENTE

2-1 Des origines de l'automatisation et des « aides intelligentes »

Longtemps centrée sur l'adéquation de l'environnement de travail aux capacités psychophysiologiques de l'opérateur (ergonomie psychophysique), la prise en compte de l'homme dans les conceptions de systèmes complexes a subi une nette évolution au début des années 80 avec le développement des automatismes et des "aides intelligentes".
L'objectif n'était plus d'adapter des outils ou des conditions de travail, mais de répartir le travail différemment entre l'homme et la machine, et de prendre en charge les secteurs de la tâche où l'opérateur était jugé limité ou peu fiable. Certes, l'idée d'aide à l'opérateur préexistait déjà à cette révolution. Mais l'aide avait jusque là toujours été considérée comme passive, servant l'opérateur comme un esclave, prolongeant sa main mais pas son cerveau; la révolution cognitive allait permettre à la fin des années 60 que cette aide devienne intelligente, se mêle véritablement à la réalisation du travail de l'opérateur, fasse parfois doublon avec lui en interagissant au niveau de ce qu'il possède de plus noble : son savoir-faire.
On ne peut comprendre ce type d'évolution sans évoquer le type de modèle de l'opérateur qui "habitaient" les ingénieurs de conception de l'époque. C'est ce modèle, et particulièrement ses faiblesses supposés, qui expliquent les choix qui ont été faits et optimisés au cours des dix dernières années.
Ce modèle était infiniment simple: l'opérateur est compris comme un système à capacités limitées, ne pouvant faire qu'une chose à la fois, rapidement débordé par la (sur)charge de travail. Il est aussi compris comme un être intelligent (preneur de décision) mais particulièrement inconstant si bien que pour de nombreuses raisons il est difficile de lui faire confiance et encore moins d'espérer le voir s'adapter à des situations de plus en plus exigeantes du fait de la complexité de l'environnement. Les statistiques, qui continuent à imputer de 65 à 80% des causes d'accidents/incidents aux opérateurs de première ligne, aussi bien dans l'aviation que dans les autres techniques de pointe, renforcent naturellement ce point de vue [1] .

Deux voies s'offraient alors comme des solutions naturelles : d'une part décharger l'opérateur d'une partie du travail dit répétitif et pour lequel il était considéré comme peu fiable et d'autre part l'aider pour le travail intellectuel qui lui restait à assumer, les décisions essentiellement.

Communication présentée lors de la réunion des spécialistes RTO HFM sur «Les facteurs humains au 21^{e} siècle», organisé à Paris, en France, du 11 au 13 juin 2001, et éditée dans RTO-MP-077.

Chacun reconnaîtra le paysage des systèmes modernes dans ses deux évolutions : plus d'automatisation et plus d'assistance sous toutes formes pour prendre (mieux, plus vite) les décisions qui s'imposent en fonction du contexte et commettre moins d'erreurs qui polluent la performance dans la tâche, même si ces erreurs ne sont pas catastrophiques.

L'aéronautique civile et militaire offre un champ d'exemples de ces réalisations que nulle autre industrie de transformation ou de transport à risques ne peut égaler. On y a vu se développer des aides au pilotage, puis à la gestion de l’armement, et le futur pourrait être encore plus sophistiqué avec des automates de vol de type drones uniquement supervisés à distance par les humains pour leurs fonctions les plus critiques[2].

Chacun notera un autre point important de ces évolutions: la motivation première en aéronautique a toujours été l'augmentation de performance. En fait, la préoccupation sécuritaire a toujours été prise en compte mais de façon utilitaire, dans la mesure où les concepteurs voulaient faire faire plus à l'opérateur et que ce résultat était impossible sans risquer une multiplications des erreurs. L'aide devait permettre de franchir ce nouveau cap de performance sans détérioration de la sécurité. Certains règlements en aéronautique civile ont d'ailleurs contribué à cette logique. L'exemple type en est le règlement de base de la certification civile (JAR 25-1309) qui exige que tout nouveau système fasse la preuve qu'il procure une sécurité au moins égale à la sécurité actuelle. Fatalement l'interprétation d'un tel règlement a souvent été minimaliste (faire la preuve que le système n'est pas plus dangereux que le précédent).

2-2 La définition de l’automatisation

L'automatisation des cockpits n'est pas nouvelle. Les pilotes automatiques existent depuis bientôt 50 ans. Mais l'amélioration considérable de la performance des calculateurs a permis leur utilisation généralisée à bord des avions et, du même coup, a transformé de nombreux aspects du travail des équipages. La diversification des équipements entre automates, automatismes et systèmes d'aides au pilotage, le nombre des sous-systèmes concernés et leur précision accrue, la dissémination dans toutes les sphères techniques, et notamment les systèmes d’armes et de guidage, ainsi que la transformation des liens entre les différentes composantes de l'avion caractérisent aujourd'hui les avions très automatisés.

L'automatisation peut se définir comme toute aide qui effectue en série ou en parallèle de l'opérateur des opérations de tri, de décision, et d’action habituellement dévolues à cet opérateur (où qui furent à un moment dévolues à l’opérateur); avec une telle définition, les automates sont extrêmement nombreux dans un aéronef.
Dans la suite du texte nous limiterons notre analyse aux cas d'automatismes qui relèvent d'une option et d’un choix pour l'opérateur qui peut ou non utiliser le système. On regroupe sous cette catégorie d’automates la plupart des ‘automatismes intelligents de haut niveau’. Dans ces cas, c’est un savoir-faire qui habite l'aide ou l'automatisme, une partie de conduite, de diagnostic ou de décision qui appartenait à l'opérateur et qui maintenant anime aussi l'outil et lui donne un statut de coéquipier.
Et c'est bien là où commencent les difficultés. L' automatisme, parce qu'il doté de savoir-faire, réclame un soin particulier dans son couplage à l'opérateur humain; elle est un partenaire et non un outil; un partenaire singulier doté d'un comportement éloigné d'un coéquipier humain.

3- LE BILAN GLOBAL: MOITIE SUCCES, MOITIE ECHEC

Les résultats en matière d'automatisation sont mitigés. L'épreuve des faits aura donné définitivement tord aux optimistes inconditionnels qui prédisaient à l'aube des années 70 une formidable amélioration de la performance et de la sécurité avec l'introduction radicale de l'automatisation et des aides.
La sécurité, bien qu'exceptionnelle, ne s'est plus améliorée dans l'aéronautique civile depuis vingt ans et pourrait même légèrement s'aggraver [3] alors que les systèmes d'aide ont été développés justement dans cette période, et ce résultat est relativement applicable à toutes les industries à risques, les transports publics, et l'aéronautique militaire modulo un certain décalage temporel.
Bien sûr, ce n'est pas pour cela que le bilan des aides est négatif puisque la performance a augmenté dans des proportions remarquables à sécurité constante. Ce sont les causes de cette dissociation qu'il convient d'expliquer à la lumière de vingt ans d'expérience pour préparer l'avenir.

La cause historique de la difficulté de couplage des aides avec l'opérateur est évidemment liée au caractère très inexact du modèle de l'opérateur, décrit dans le premier paragraphe, qui "habitait" les ingénieurs de bureaux d'études pendant ces vingt dernières années.

3.1 Vers un modèle plus exact de l'opérateur [4]

Depuis près de vingt ans, la psychologie cognitive a fait de l’analyse des défaillances, des erreurs et de l’ étude des opérateurs novices des modes d’accès privilégiés à la compréhension des mécanismes cognitifs complexes, notamment du contrôle cognitif [5,6]. Le contrôle cognitif doit ici être compris comme toute activité de supervision, interne à la cognition, dont l’objectif est d’assurer et de vérifier le bon usage des capacités cognitives aussi bien en terme d’intensité, que d’ordonnancement dans le temps, afin d’atteindre le ou les objectifs visés par le sujet.
Les apports de ce type de recherche ne sont plus à démontrer. Les théories sur le contrôle de l’attention, sur la décision, et sur les modes de contrôle cognitif, reposent sur le paradigme de la défaillance -ou du biais cognitif [7]. Les catastrophes industrielles ont largement participé à cet engouement général pour l’étude des défaillances humaines.
Mais à force de se centrer sur les défaillances, des ambiguïtés durables se sont installées sur les modèles de l’opérateur. On a confondu erreur et accident, et on a diabolisé toute défaillance dans une quête d’optimalité d’un système cognitif assimilé au fonctionnement d’une machine. On a minimisé pendant vingt ans le rôle structurant de l’erreur dans la résolution de problème, pourtant évoqué dès les années 40 par les Gestaltistes. On a aussi négligé l’accumulation de résultats démontrant que l’opérateur commet beaucoup d’erreurs, mais en récupère la plupart [8,9].
Reason [5] lui-même n’a pas restauré un visage positif de l’opérateur dans son premier livre sur l’erreur. Son argumentaire sur la rationalité limitée et les primitives cognitives vise à expliquer la « normalité » de la survenue de l’erreur, plus qu’elle ne cherche à en comprendre l’utilité. Quant à la démonstration de sécurité systémique, Reason a simplement déplacé la faute de l’opérateur de première ligne pour la faire peser sur les hommes responsables de la conception et de l’organisation[1].
Il a fallu attendre des temps plus favorables pour changer le mode de pensée dominante; le basculement est intervenu dans le milieu des années 90 avec l’augmentation des études de terrains en situations très complexes. Parallèlement, l’industrie s’est aperçue que le taux d’accident se mettait en plateau : l’optimisation des solutions de blocage des erreurs et d’encadrement de l’opérateur avait des limites .
Toutes les conditions étaient réunies pour une bascule théorique et pratique concernant les idées développées sur la fiabilité humaine.

En quelques années, le paysage de la recherche a changé, avec une révision profonde du concept d’optimalité du fonctionnement cognitif (mais qui n’a souvent fait que reprendre des théories pré-existantes négligées):

- L’optimalité cognitive ne doit plus se décliner en termes de recherche de fonctionnement à moindre déchet, et particulièrement de moindre déchet instantané (évitement de toute erreur et défaillance, temps de réponse minimal, compréhension maximale, récupération des défauts dès que détectés), une hypothèse pourtant dominante depuis des décades dans les protocoles expérimentaux, les consignes, et toutes les disciplines intéressées à la sécurité,
- Elle se décline plutôt en terme de compromis permettant une atteinte *dynamique* de l’objectif (mais on devrait dire « des » objectifs) avec une performance suffisante. Trois idées sont centrales dans cette révision théorique :
  - Celle de « suffisance », mais elle est souvent comprise- à tort- comme minimaliste (moindre coût cognitif) ; elle doit plutôt être comprise comme une réponse adaptée à l’environnement apportant une satisfaction subjective à celui qui fait le travail, compte tenu de ses buts, du contexte, et de ce qu’il sait faire. La notion de ‘suffisance’ est reconsidérée à chaque exécution, et n’est pas contradictoire avec une performance très élevée et un coût cognitif élevé.

[1] Reason a infléchi récemment ce point de vue ; son dernier ouvrage de 1997 donne une place plus importante à l’utilité cognitive de l’erreur, et à la contribution à la sécurité des acteurs de première ligne

- Celle d'adaptation dynamique, avec des fluctuations importantes de performance dans le temps, mais finalement une réponse globale acceptable à l'échéance visée; le temps disponible et les échéances visées sont les unités sur lesquelles il faut juger la performance cognitive, et non le résultat à chaque instant de ce temps disponible avant que les échéances ne soient atteintes. Les erreurs s'avèrent n'être finalement que le prix à payer à un compromis bien contrôlé, et ne sont souvent que des variables secondaires dans la maîtrise de la situation.
- Enfin celle de métacognition, qui permet de régler la gestion des risques acceptables et acceptés, et notamment du contrat de performance de départ.

3.2 Les causes de la difficulté du couplage des "aides intelligentes"

Quatre variables sont déterminantes pour qualifier un système d'aide et en réussir -ou pas- le couplage à l'opérateur: la qualité de compréhension, la qualité de la confiance, la conscience du niveau de risque accepté et une définition claire des responsabilités.

3.2.1 Le niveau et la qualité de la compréhension

Dans la plupart des cas le "traitement" facteur humain de l'automatisation se limite à présenter l'information sous une forme familière à l'opérateur, rapide à comprendre. Mais trop souvent les automatismes apparaissent comme "magiques", "opaques" à l'opérateur dans la façon dont ils élaborent l'information, proposent la solution et jouent cette solution.

Pour contourner cette difficulté, de nombreux travaux soulignent l'importance de doter les machines d'un comportement le plus "humain" possible afin de faciliter leur compréhension et leur utilisation par l'opérateur. Le concept dominant est celui de la programmation des systèmes "centrée sur l'homme", "transparente", "human-like", en bref respectant les modèles psychologiques de l'utilisateur [10, 11].
Les principaux résultats en faveur de ce concept soulignent que plus l'opérateur est novice ou passif, plus ses interactions sont non pertinentes vis à vis du problème à traiter. Lehner [12] ajoute que plus l'opérateur est naïf vis à vis du système d'assistance, plus une similarité des connaissances et des raisonnements entre le système et l'utilisateur est nécessaire pour qu'il suive le fonctionnement du système automatique et reprenne la main quand nécessaire.
Plusieurs résultats [13] convergent aussi pour montrer qu'il est nécessaire de donner une compréhension minimale des principes de fonctionnement du système afin d'éviter des interprétations magiques de la part de l'opérateur. L'automatisme ne doit pas être présenté comme une boite noire et doit faire l'objet d'un enseignement formel au même titre que les connaissances sur les lois de vols ou les lois des systèmes hydrauliques.
Mais le point central de la critique est la notion d'optimalité des automatismes. Les automatismes sont en effet conçus pour donner le résultat le plus élevé dans l'absolu à chaque pas de leur exécution, ce qui est rarement le résultat d'une performance humaine dans une situation comparable. L'optimalité humaine se décline sur l'objectif. Par contre, à chaque instant, la 'copie cognitive' est comme un devoir inachevé. Le sujet est conscient qu'il n'a pas tout compris, pas tout fait ce qu'il aurait fallu faire, et qu'il a commis des erreurs qu'il n'a pas encore récupérées. Cette sphère de conscience de « l'inachevé » ordonne des priorités cognitives, et explique souvent des déviances, qui n'ont pour seuls buts que de se donner plus de temps pour récupérer des retards. Cette notion de brouillon inachevé est indispensable à la gestion dynamique de la cognition, et s'avère performante sur le but (malgré toute cette imperfection de chaque instant, le résultat est le plus souvent correct) ; mais elle créé aussi beaucoup de difficultés dans la conception et le couplage aux aides, car ces dernières sont souvent très directives dans la correction immédiate des défauts et perturbent gravement –en voulant bien faire- le réglage de la gestion dynamique des risques. Là encore vouloir forcer l'opérateur à travailler constamment en performance optimale est un non-sens psychologique et ergonomique[4].

3.2.2 La confiance

Quand l'automatisme se comporte de façon opaque, les mécanismes naturels de confiance ont du mal à s'établir et l'opérateur hésite en à reprendre la main sur le système, à la fois parce qu'il sublime le coté magique de l'aide et qu'il doute de lui et de ses capacités à faire aussi bien s'il reprenait la main[14,15].

3.2.3 Le niveau de risque accepté

Au delà de ces difficultés de couplage, deux autres paradoxes importants font obstacle à la conception actuelle des systèmes automatiques réellement compatibles avec une augmentation de la sécurité:

Paradoxe 1: La plupart des automatismes ne savent gérer que les situations normales. On compte toujours sur l'opérateur pour récupérer les situations anormales, qui sont justement les plus complexes.
Paradoxe 2 : Les automatismes poussent en permanence l'opérateur à optimiser la minimisation du risque externe, objectif, sans prendre en compte les efforts cognitifs nécessaires à cette optimisation, ni le répertoire de réponse de l'usager. La conséquence en est souvent une charge de travail excessive, non pas liée à l'automatisme mais à l'ambition de performance et l'augmentation des exigences de la situation, que l'opérateur essaie malgré tout de contrôler à un niveau plus acceptable en réduisant l'espace problème pris en compte et en diminuant les contrôles qu'il effectuerait spontanément sur le système. La conséquence d'une telle approche est logiquement l'augmentation de la fréquence des erreurs humaines non détectées [16] .

3.2.4 La responsabilité

Les difficultés ne s'arrêtent pas à un simple analyse technique. Le problème de la responsabilité de l'opérateur de première ligne en cas d'erreur -ou pire d'accident- quand cet opérateur est assisté d'un ou plusieurs systèmes d'aides est un véritable casse-tête social et juridique pour le secteur civil. Cette situation s'applique aussi aux défaillances graves des systèmes d'armes automatisés.
Normalement, les aides sont un choix de l'opérateur. La responsabilité dans la performance finale est donc clairement à charge de cet opérateur. Mais les choses se compliquent pour deux raisons: d'une part la conduite avec automatismes est fortement encouragée voire obligatoire afin d'assurer le maximum de sécurité et de performance. Quand une erreur est commise dans les interactions avec les automatismes suite à une incompréhension du fonctionnement de l'automatisme, la faute incombe souvent à l'opérateur et non à la conception de l'automatisme. D'autre part, les systèmes d'aides ou de conseils prennent également un statut de "parole de Dieu". Leur contestation par le pilote dans une phase de vol incidentelle ou accidentelle est la plupart du temps considérée comme un erreur par la commission d'enquête. Bref, la responsabilité est toujours sur le pilote, mais la décision est de plus en plus, pour les raisons évoquées précédemment d'opacité et d'optimisation, du coté du système. Il en résulte un difficile débat juridique sur la responsabilité finale de la faute avec ces systèmes qui entrent véritablement en compétition avec l'opérateur dans ce qu'on lui a toujours reconnu de plus précieux : sa capacité décisionnelle.
Pour toutes ces raisons, la réalité des incidents / accidents récents montrent que les opérateurs sont de moins en moins tentés se désobéir aux conseils de ces machines.
Mais est-ce là vraiment ce que l'on cherche, vu les attentes sur la présence de l'homme à bord et le coût d'embarquement de cet opérateur humain par rapport à un drone?

4- PERSPECTIVES

4-1 Plaidoyer pour une sécurité plus écologique

Le modèle de sécurité écologique décrit dans les paragraphes précédents de cet article ne garantit pas une sécurité totale. Il porte en lui les germes de défaillances potentielles très sévères. Mais il permet de comprendre différemment ces défaillances par rapport aux modèles classiques d'erreurs.
L'hypothèse de base repose sur une cognition qui 'veut survivre' et qui se donne les moyens de sa sécurité ; l'erreur ou la défaillance grave doivent être évitées. Mais elle se doit aussi d'être efficace ; une position maximaliste en contrôle complet et permanent de la performance réduit considérablement le potentiel de performance cognitif. Le système cognitif s'est donc configuré dynamiquement pour répondre à ces deux objectifs contradictoires.
Cette configuration repose sur deux piliers : (i) s'adosser à l'émergence naturelle de signaux cognitifs pour procéder aux corrections tactiques quand la cognition atteint les premières limites de contrôlabilité (encore aisément récupérables, donc avec des marges) [4]; (ii) s'appuyer sur la métacognition pour gérer le caractère stratégique et garder le contrat d'objectif dans une zone effectivement réalisable (par expérience).

Les défaillances graves surviennent quand un de ces deux piliers est parasité, soit que les signaux de limites soient masqués ou que la métacognition indique des capacités erronées de gestion. Ces deux conditions sont

souvent remplies dans une automatisation des systèmes : d'une part, les automatismes masquent la perte de contrôle cognitive en garantissant une performance maximale même sans intervention et compréhension de l'opérateur ; d'autre part, les connaissances de l'opérateur sur le système deviennent plus hétérogènes du fait de l'accroissement de la complexité globale; les mécanismes de mémoire et de métaconnaissance finissent par gommer une partie de cette hétérogénéité et font croire à l'opérateur qu'il en sait plus que la réalité de sa cognition [4].

4-2 La conception d'automatismes qui respecte l'écologie de la maîtrise de la situation par l'homme

Le titre de l'article portait sur la conception d'automatismes et les systèmes tolérants aux erreurs. Le texte a montré que les automatismes introduits dans l'aéronautique dans les vingt dernières années ont considérablement augmenté la performance tant sur le terrain civil que militaire. Inversement, ils n'ont pas significativement changé le niveau de sécurité ; leur introduction a réduit mécaniquement les erreurs de routines (puisque l'opérateur touche moins aux commandes), mais elle a été la source de nouvelles erreurs de compréhension, dont on sait qu'elles sont particulièrement accidentogènes.

A ce niveau de couplage, de sécurité, et de performance, les leçons à retenir pour une conception plus harmonieuse sont multiples :

- Nous sommes encore à un moment où les automatismes ont besoin de l'homme pour les valider et les surveiller. Dans ces conditions, les équilibres écologiques entre logique de performance et logique de couplage à l'homme sont prioritaires à (re) trouver. La conception actuelle, par négligence des besoins humains, propose des solutions optimisées en performance, rigides dans leur mises en oeuvre, pléthoriques en options, et finalement opaques pour l'opérateur et sources d'erreurs graves. La seule façon de les coupler mieux à l'opérateur est de revoir ces critères : les réduire en nombre, surtout quand elles ne sont que des options même pas enseignées (exemple des modes du pilote automatique), les rendre plus souples avec un fonctionnement optimal sur l'objectif, et non de chaque instant, bref, les rendre plus inspirées du modèle de fonctionnement humain.
- La performance pourrait se trouver limitée par cet effort couplage plus harmonieux ; c'est sans doute le prix à payer à une optimisation de sécurité dans la situation actuelle. Performance et sécurité sont des variables qui divergent en optimisation de systèmes. Pour cette raison, on conçoit que les arbitrages puissent être différents entre applications civiles et militaires.
- Les solutions du futur n'élimineront jamais l'homme dans la supervision des systèmes ; cet homme va changer de rôle, mais être encore plus essentiel à l'obtention de la performance du système, vu le faible nombre d'opérateur envisagé, et leur criticité de décision.
- Les robots seront parmi nous en grand nombre dans moins de 20 ans, ils sont déjà utilisés (exemple des opérations de la guerre du Kosovo); ce phénomène ne sera pas limité aux drones ; il va toucher progressivement l'ensemble des outils de proximité des forces, et plus généralement de notre société (assistance diverses, véhicules terrestres automatiques, et même techniques médico-chirurgicales, etc). Il sont une forme d'ultime conséquence de la révolution de l'informatique, des moyens de communications, et du contrôle des transmissions à distance à grande échelle, haut débit, et haute sécurité. Comme toujours dans de tels programmes, les premières années de conception sont des années de défis techniques ; il faut trouver les solutions techniques adéquates pour faire vivre le concept. Mais on est déjà presque au delà de cette période. IL faudra conduire impérativement et en même temps une réflexion encore plus amont pour anticiper les changements très profonds de culture qui vont résulter dans nos forces de l'usage de ces technologies. Encore une fois, les impacts sociologiques sur les Armées, et organisationnels devraient être considérables à terme. Les théories les plus modernes de l'ergonomie cognitive et de la coopération doivent être mobilisées pour résoudre ces problèmes au mieux.

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Diving, Submarine Escape and Rescue: The Medical Issues

Surgeon Commander M A Glover
Medical Officer (Diving Medicine)
Institute of Naval Medicine
Crescent Road, Alverstoke
GOSPORT
Hampshire, PO12 2DL
United Kingdom

Summary: This presentation gives an overview of problems experienced by submariners trapped underwater and diving casualties. The primary topics are decompression illness and the equipment and organisation in place and planned for the future to improve the outcome of these incidents.

Keywords: Diving, Submarine Escape and Rescue, Decompression Illness

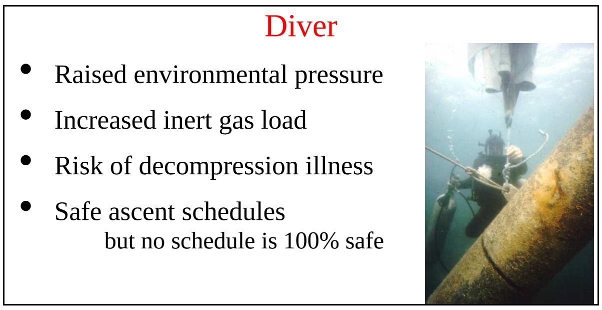
Slide 1 (Title)

Good Morning Ladies and Gentlemen,

I am Surgeon Commander Mark Glover, currently working in the Undersea Medicine Division of the Institute of Naval Medicine in the United Kingdom. In this presentation I intend to give you an overview of the current medical issues pertinent to the care of individuals who are immersed or working in ambient pressures above 1 atmosphere.

Although many of the examples in this presentation are from the United Kingdom, I would like to remind you that other nations have similar equipment and organisations that are inter-operable and will enable a multi-national response to a diving or submarine incident.

Slide 2



First, some background. For every 10 metres a diver descends in seawater the ambient pressure rises by 1 atmosphere. As ambient pressure increases gases are compressed and more is dissolved in living tissues. As the diver surfaces pressure decreases, gases expand and, if the excess volume can escape freely from gas filled spaces, no injury will occur. Similarly if the excess gas dissolved in the tissues can be released and carried by the circulation from the tissues without forming bubbles then no harm will occur. If bubbles form then further gas elimination is compromised and expansion of the bubbles can crush, block and tear apart structures causing both microscopic and gross damage to vital organs. The bubbles, however transient, can also initiate potent inflammatory and other biochemical processes.

Paper presented at the RTO HFM Specialists' Meeting on "Human Factors in the 21st Century", held in Paris, France, 11-13 June 2001, and published in RTO-MP-077.

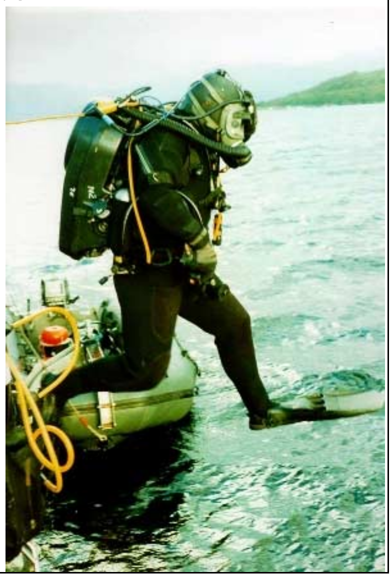
Whatever the precise mechanism the clinical manifestation is termed decompression illness. This illness can affect multiple systems and is notoriously unpredictable in its outcome, which can vary from minor symptoms that are frequently dismissed to rapid onset, life-threatening symptoms. It is possible to generalise, however, that the more gas accumulated in tissues and the more rapid the reduction in ambient pressure, the more severe the illness that results.

The probability of decompression illness can be minimised by limiting the amount of gas dissolved in the tissues and ensuring that ambient pressure drops at a rate that liberates gas in quantities that the body can cope with. Even if decompression schedules are adhered to, it is recognised that none are 100% safe.

Slide 3

Diver

- Gas toxicity
- Equipment failure
- Hostile environment
  - impaired communication
  - poor visibility
  - cold
  - mechanical hazards
    - foreseen and unforeseen
    - wildlife and inanimate



A diver is subject to multiple hazards in addition to the ambient pressure. If the mixture is incorrect, then breathing gases can be toxic. A mixture which is safe in other circumstances may induce nitrogen narcosis, oxygen toxicity, hypoxia or other well recognised toxic phenomena if it is breathed at an inappropriate ambient pressure.

Equipment can fail in many ways and the environment is hostile, not least because the diver cannot breathe water. Difficulty in communication, poor visibility and thermal problems can handicap performance significantly. Hazards such as strong currents, explosions and dangerous wildlife can be foreseen or unforeseen. In the event of a problem the diver will invariably want to return to a place of safety. This is usually the surface and the accumulation of inert gas in the body with resultant decompression obligation can make an immediate return unsafe.

Slide 4

In the event of decompression illness or if the diver has undertaken insufficient decompression stops in-water then recompression in a chamber, usually breathing a high partial pressure of oxygen, is the only effective established treatment.

Appropriate first aid consists of the standard approach of airway, breathing and circulation with the addition of fluids and high inspired partial pressures of oxygen.

Until recently Royal Navy divers deployed on minehunters have depended on one man recompression chambers. These allow recompression and, if required, transport to a more capable facility. The one man chamber is mated onto the larger one and the diver is then transferred without being decompressed prematurely.

Slide 5

Type 'C' Chamber

One man chambers have considerable limitations. For instance, if the diver's health deteriorates there is no option of assistance without decompressing the chamber. Royal Navy minehunters are now being fitted with 2 compartment chambers capable of supporting deep heliox diving. If the therapeutic gases for deep decompression tables were delivered by open circuit the amount required would far exceed the storage capacity of the minehunter so, in order to overcome this problem, the Type C chamber has a rebreather system installed.

As well as being fitted to minehunters, several of these chambers have been containerised to allow them to be deployed quickly on larger ships or on land.

Slide 6

Submarine Accident

- Survivors trapped, possibly at pressure
- Mechanical trauma
- Thermal injuries
- Deteriorating atmosphere
- Cold
- Radiation
- Starvation / Dehydration

Also we must consider the, sadly topical, plight of a submarine stranded at depth. The initial accident is likely to involve explosion, collision or fire. Mechanical and thermal injuries are likely and will require surgical and medical attention. If the atmosphere within the submarine is not already contaminated by smoke or escape of stored gases, it will slowly deteriorate as oxygen is consumed and carbon dioxide accumulates as a product of respiration. If the submarine is nuclear powered the crew might also be subject to radiation injuries. In most waters the interior will rapidly cool to a few degrees above freezing so the crew risk hypothermia. This risk is likely to increase if the hull has flooded. Alternatively, in some circumstances, heat exhaustion could occur. Finally, if supplies of water and food run out then starvation and dehydration are unavoidable. Many of these problems can be minimised by good planning and provision for survivors. Oxygen can be monitored and added. Carbon dioxide can be monitored and removed. Dry, waterproof clothing will reduce the chances of hypothermia.

Slide 7

Pressure - Solutions

- Avoid pressure exposure altogether
  - rescue
- Minimise pressure change
  - rescue from pressurised environment
    - decompression schedule
    - deliver to pressurised receiving area
    - surface and recompress
- Minimise extra gas load
  - escape

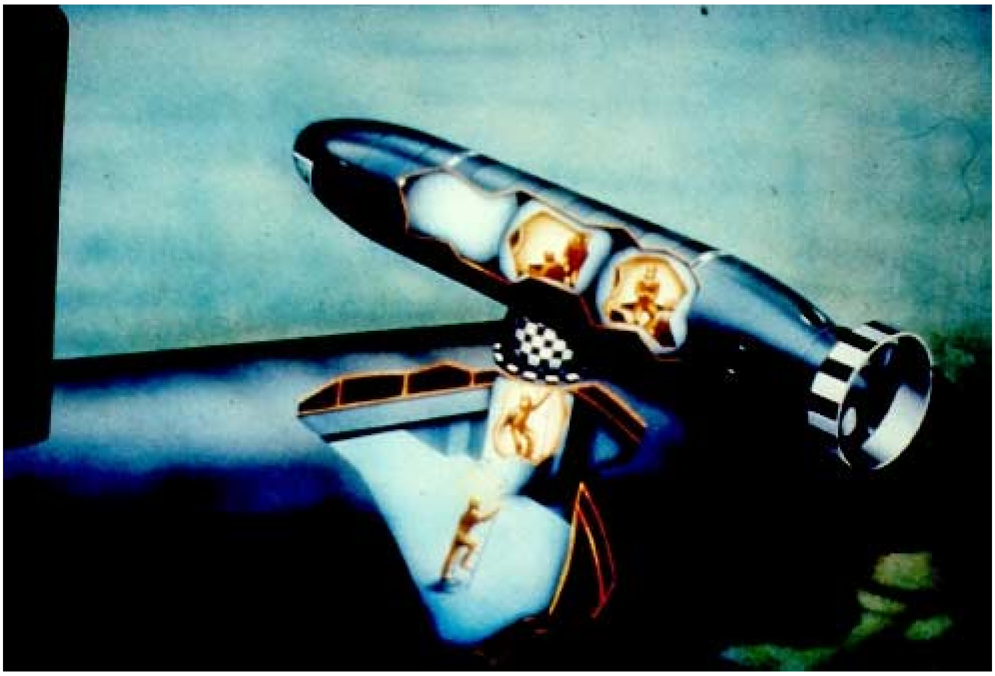
As in diving, pressure change is a major consideration in submarine escape.

From a preventive standpoint, candidates for diving and submarine service should be free of any conditions that might compromise their tolerance of pressure-related volume changes, such as obstructive airways disease and middle ear problems.

The probability of decompression illness can be minimised by limiting the amount of gas dissolved in the tissues and ensuring that ambient pressure drops at a rate that liberates gas at a rate that the body can cope with.

Pressure change can be avoided altogether if the submarine hull is not breached so the internal pressure remains close to surface pressure. In this case a transfer from the submarine to surface with no pressure exposure will be associated with no risk of decompression illness. This is possible using a submersible vessel specially designed to mate with the escape hatch of the submarine. A variety of such vessels are available, ranging from a "bell" lowered from surface along a guide wire, to self-propelled vehicles. These can be piloted or remotely operated: most begin their rescue mission by launching from a surface ship and are, therefore, vulnerable to rough sea conditions. Some are carried by other submarines and make the transfer from submerged vessel to submerged vessel.

Slide 8



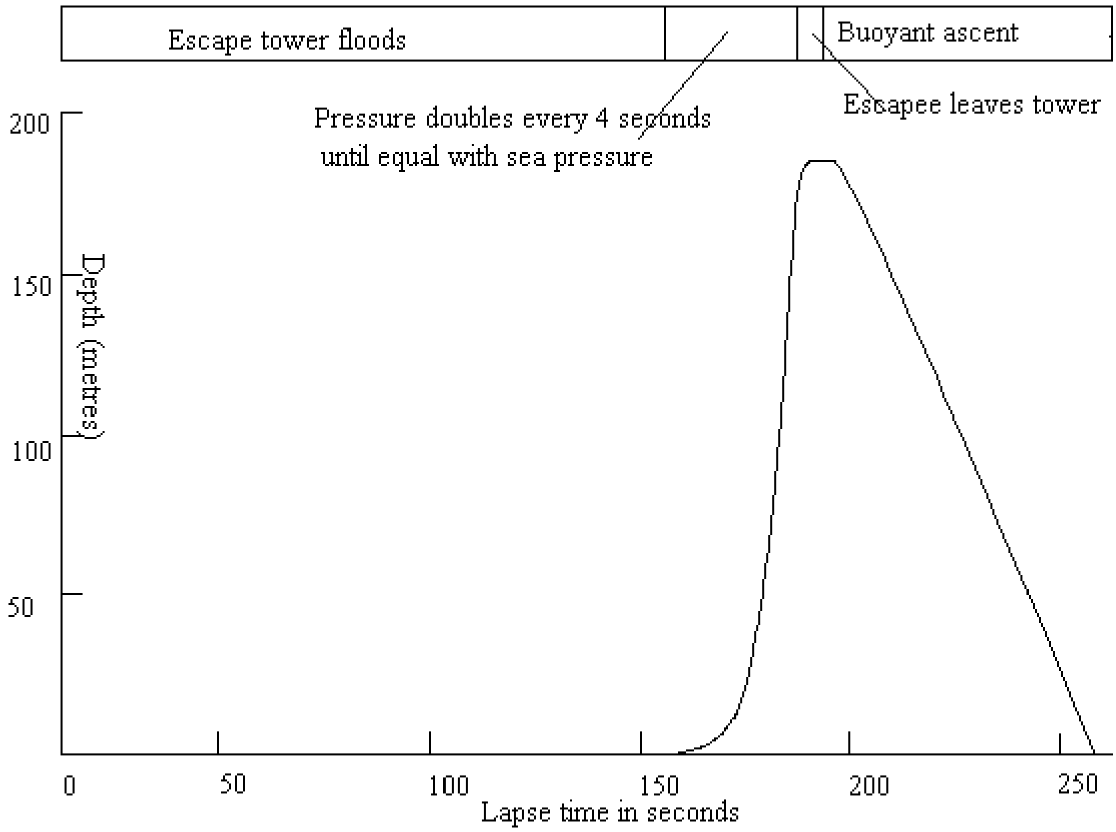
A rescue that avoids pressure change for the survivors is the ideal situation.

There is a chance, however, that the submarine becomes pressurised, for instance if the hull is compromised and the main compartment floods partially, and this will complicate escape and rescue by increasing the risk of decompression illness.

This has been addressed in a number of ways. If the crew can be rescued then it is possible to transfer them at raised pressure and to decompress them at a safe rate. The decompression can be accelerated by the use of high inspired partial pressures of oxygen. The rescue vessels might not be large enough to take all the survivors in one load so, in order that time is not wasted decompressing survivors on the rescue vessel, the support vessels can be fitted with decompression facilities.

Rescue is required when the disabled submarine is at greater than 180 metres depth or pressurised past the safe limit. Surface conditions will dictate which rescue assets, if any, can be used but rescue is always the preferred procedure if conditions on the disabled submarine allow survivors to wait on board.

Slide 9



Rescue assets take time to collect at the incident scene, however, and there are many reasons why it might not be possible to await rescue, such as fire, flood, radiation and deterioration in atmosphere. Increased pressure, for instance, can result in gas toxicity which might make it impossible to stay on board the stricken submarine. In this event there is an option of escape.

Several navies fit their submarines with escape compartments which allow one or two survivors to be pressurised to the ambient depth and allow them to make an ascent to the surface assisted by buoyancy equipment. The escapees climb into the escape compartment and, once it is closed, water is admitted from the exterior pressurising the escape tower.

This pressurisation is rapid and can reach the maximum escape depth of 180 metres within 25 seconds.

Slide 10

Once the pressure in the escape tower equals the external pressure the outer hatch opens and the escapees float out and ascend towards the surface at speeds in the region of 3 metres per second. The escapees spend so short a time at pressure that they absorb very little gas in their tissues. Generally, the greatest risk is due to the inadequate escape of gas from air-filled spaces. With deep escapes, however, there is some risk of decompression illness as a result of rapid accumulation of gases in the tissues. Although it has been proven possible from 180 metres, escape carries a higher risk of injury compared with rescue.

The escape suit has an air-filled hood which allows the escapee to breathe normally throughout the ascent. If this was to flood or fail in some other way, the escapee will need to exhale all the way to the surface, as shown at top left.

Slide 11

Surface Survival

- Barotrauma
- Decompression illness
- Drowning
- Dehydration/Starvation
- Hypothermia
- Marine wildlife

- Integrated life raft
- Improved survivability

Even on reaching the surface submarine survivors and divers are faced with a range of hazards, such as seasickness with eventual dehydration, starvation, attacks from marine animals, accelerated hypothermia and drowning.

A liferaft has been provided with the latest submarine escape and immersion suits in order to enhance survival.

Slide 12

In the event of escape from a pressurised compartment the crew will undergo rapid decompression to atmospheric pressure as they float to the surface. If they have a significant risk of decompression illness or develop symptoms when they surface they can be picked up and placed in a decompression facility. Saturation at anything greater than 1.7 atmospheres absolute carries an increased risk of decompression illness.

One particularly risky procedure is the rush escape. If the crew must escape quickly the escape compartment is flooded until the remaining air, trapped above the water level, is compressed to the pressure found at the escape depth. The external hatch can then be opened and the survivors can float through the hatch immediately after one another. This is a relatively hazardous process and those who leave last will have a higher risk of decompression illness due to prolonged exposure to pressure.

If there is sufficient time to delay escape or rescue it is possible to refresh the atmosphere in the stricken submarine via a hose from the surface, and even to depressurise the hull at a safe rate prior to rescue or escape.

Slide 13

Medical Planning

- Minimise decompression illness incidence
  - safe to escape criteria
  - accelerated decompression schedules
  - preventive recompression
- Prepare for decompression illness
- Prepare for other injuries
- Prepare for mixed injuries
- Early assistance

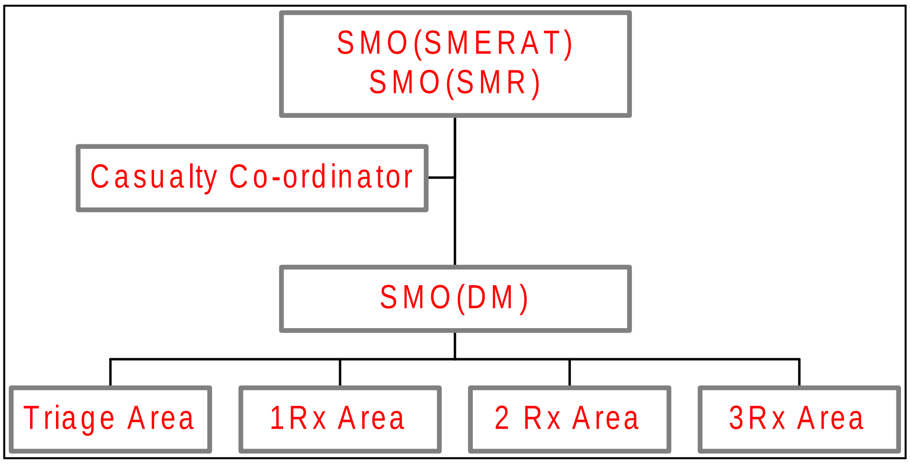
There are several areas of research into minimisation of the incidence of decompression illness, varying from establishment of safe to escape criteria for varying levels of exposure, gas mixtures breathed pre- and post-escape, and use of drugs.

If depressurisation is too rapid and the individual risks decompression illness or develops symptoms then the primary treatment is recompression. Other supportive treatments might be indicated but none have been identified as being as effective as recompression. Rehydration and supplemental oxygen are mandatory first aid measures even if recompression is not available.

Medical teams should be capable of dealing with casualties with both decompression and other injuries. Similarly, medical equipment and staff should be safe for employment in recompression facilities.

Slide 14

SMERAT



The Submarine Escape and Rescue Assistance Team ideally consists of a group of specialists in the fields of Submarine Escape and Rescue, Submarine Medicine and Diving Medicine. The team is augmented by other personnel with experience in submarine escape, compression chamber operation, use of escape and rescue equipment and recovery boat work.

A team appropriate to the scale and nature of the incident is convened by a system of pagers and telephone callout and is deployed to the incident site as rapidly as possible.

Slide 15

SPAG

If very early assistance is required the SUBSUNK Parachute Assistance Group can be dropped by parachute at the scene of an accident to provide emergency aid. The group has inflatable boats and carries medical gear including oxygen administration equipment. In addition, sufficient 25-man liferafts are airdropped to allow the entire crew of the disabled submarine to be recovered from the water.

Slide 16

First Reaction Stores

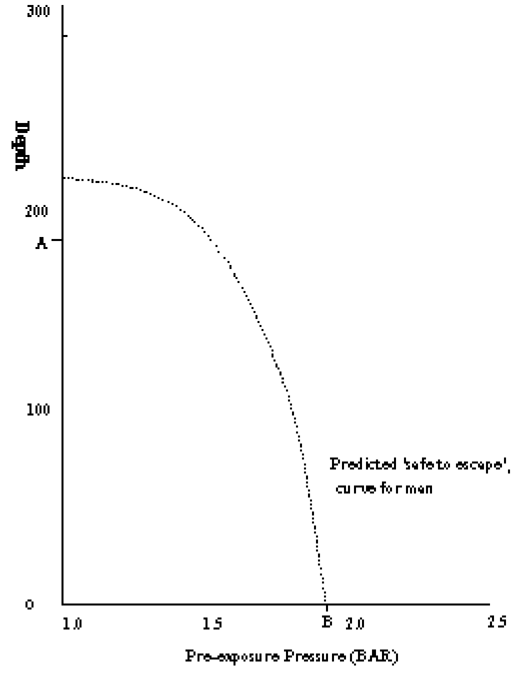
First reaction stores, comprising medical supplies and recompression chambers are kept in several widely dispersed locations to minimise the distance needed to transport one of them to a nominated ship, the Escape Gear Ship.

Once embarked on the Escape Gear Ship the team and supplies travel to the incident area. Triage and treatment areas and personnel are organised alongside casualty evacuation plans and assets. Preparation is made for decontamination of survivors who may have come into contact with radioactive products. Recompression chambers are prepared and the team awaits the first rescuees or escapees.

In summary, raised environmental pressure is an inevitable and unique aspect of escape or rescue from a submerged vessel. This carries a significant risk of morbidity and mortality and rescue must either protect the survivor from pressure altogether or techniques must be adopted to prevent or treat the consequences of pressure change.

It is clear that optimum planning for evacuation of survivors from a hyperbaric environment will necessitate provision of a recompression facility. Even if there is negligible inert gas load, there is still a risk of pulmonary barotrauma and subsequent arterial gas embolism from pressure changes associated with depth excursions as small as 1 metre. As stated earlier, casualties might have injuries of multiple origin. As a result triage must take account of the need for recompression as well as treatment of the other injuries.

Slide 17



Where should future work be directed? The decision on whether to escape or await rescue can be enhanced to improve overall survival, for instance by development of detailed safe escape criteria.

There are two well known points on the safe to escape curve. Escape from a submarine at 1 atmosphere has been proven at depths of 180 metres. Also, humans can surface from saturation at pressures up to 1.7 atmospheres before decompression illness becomes a significant risk. The submarine escape simulator facility was designed and built by the UK Ministry of Defence to investigate the intermediate points of saturation pressure and escape depth on the safe-to-escape curve while maximising the safety of simulated escape pressure profiles. The chamber consists of two interconnected spheres. One, the 3m diameter sphere, acts a s the reservoir for the gas the other, the 2 m diameter sphere, as the test chamber. They are connected by a 10 cm internal diameter pipe. The control valve on this pipe is operated by a computer system which also monitors the condition of the system and will abort a pressure profile if it is out of specification. Subjects enter the 3 m sphere for the saturation element of the profile and then enter the 2 m sphere the simulated escape.

Slide 18

Ways Forward for the 21st Century

- Detailed safe escape criteria
- Relevant decompression schedules
- Accelerated decompression
- Use of drugs and gases in prevention and treatment of decompression illness
- Integration of care of mixed injuries resulting from decompression and other hazards

There is still room for further research into safe and time-economical decompression schedules for both divers and submariners. Drugs and gas mixes need to be assessed for their role in both prevention and treatment of decompression illness.

There have been significant advances in the treatment of many conditions and injuries and consideration must be given to integration and optimisation of care of mixed injuries requiring both urgent recompression and other life-saving attention.

Diving and submarine service have probably never been safer, but this is no excuse for complacency as there is considerable room for medical and physiological advances which have the potential to reap significant improvements in morbidity and mortality both within and outside the underwater environment.

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Cultural Factors in Future Multinational Military Operations

Keith G Stewart, Michael C Bonner, Neil G Verrall
Centre for Human Sciences, A50 Building
DERA Farnborough, GU14 0LX, United Kingdom

Summary
Operating in a multinational force raises a new set of challenges for the military personnel involved. The Centre for Human Sciences has a new, three year, programme of work, funded under Technology Group 5 of the UK MoD's Corporate Research Programme, the aim of which is to attempt to identify national and organisational cultural factors that have the potential to impinge on optimal multinational inter-working. This paper provides a brief introduction to a selection of these factors including communication, decision making, and interactions with technology.

Introduction

The last decade has seen increasing attention paid to multinational military forces. Experiences in the Arabian Gulf and the former Yugoslavia have demonstrated the substantial military advantages to be gained through coalition and alliance operations. However, as commentators such as Palin (1995) have observed, multinational forces raise a new set of challenges for the military personnel involved. While the most high profile difficulties tend to involve issues such as international politics and the interoperability of military equipment, it is also possible to identify a range of factors that relate to the national and organisational cultures of the participating military forces. A good example of such an issue, cited by Palin, was the question of the role that female military personnel would be able to play during the Gulf War.

The Centre for Human Sciences has a new, three year, programme of work, funded under Technology Group 5 of the UK MoD's Corporate Research Programme, the aim of which is to attempt to identify national and organisational cultural factors that have the potential to impinge on optimal multinational inter-working. A further aim of the work is to propose practical recommendations for overcoming the vulnerabilities identified. This paper is based on an initial examination of the research area. At present, we are not in a strong position to begin to propose answers. Our current goal is to formulate the right questions. Likewise, the primary purpose of this paper is to stimulate discussion. This paper does not pretend to be an exhaustive examination of the area. Rather, a few topics have been chosen to provide a flavour of the issues involved. These relate to both organisational and national cultural issues.

Our research group's initial searches for literature bearing directly on the topic of cultural issues in multinational forces were met with only limited success. As a result, we broadened our search to include related work in areas such as business management and aviation psychology. Our hope is to learn from the study of multi-cultural operations in these commercially oriented environments. Indeed, commentators such as Toffler and Toffler (1993) have proposed that there are interesting parallels to be drawn between multinational companies which seek to establish 'strategic alliances' and 'consortia' and nation states that seek alliances, and, where crises demand, modular coalitions of military forces. In both cases the partnerships and alliances created are based on a requirement to share capabilities with a view to enhancing overall performance in a competitive global environment.

Classification of cultural differences

Culture relates to the way in which definable groups of people interact with their social and physical environment. Culture, whether relating to nations or organisations, is learned through experience. A range of factors relating to differences between national cultures can be identified. Perhaps the best known study into differences between national cultures was conducted by Hofstede in the 1970s (Hofstede, 1980). On the basis of an examination of survey responses given by 117,000 IBM employees in 40 countries, Hofstede derived a cross-cultural classification scheme of work-related values based on four dimensions. These were: 1.'Power

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distance', which relates to the amount of respect and deference between those in superior and subordinate positions; 2. 'uncertainty avoidance', which relates to planning and the creation of stability as a means for dealing with uncertainty; 3. 'individualism-collectivism' which relates to whether one's identity is defined by personal goals and achievements or by the character of the collective groups to which one belongs; and 4. 'masculinity – femininity' a dimension which, Hofstede argued refers to the relative emphasis on achievement or on interpersonal harmony. This classification scheme has provided a useful starting point for researchers for examining and categorising the apparent broad differences between national cultures. It is interesting to note that Hofstede found there to be a strong negative correlation between the individualism-collectivism and power distance dimensions. For example, Australia and New Zealand are ranked very high on individualism but low on power distance indicating a flatter authority gradient between levels in their organisations. In contrast, in cultures that Hofstede has defined as being 'collectivist', such as are found in Indonesia and the Philippines, the opposite is found, with very low individualism rankings and high power distance. One of the most interesting aspects of Hofstede's findings is that, since all the respondents were from one company, many of the potential confounding effects of organisational culture can be argued to have been removed.

It is essential to stress that the implications of Hofstede's work are not that there are good and bad cultures. Rather, this work can be used as a starting point to recognise that there are differences, to suggest how those differences might manifest themselves in an organisational setting, and to attempt to apply this knowledge in an attempt to optimise cross-cultural performance. Elron, Shamir, and Ben-Ari (1999) have demonstrated that by drawing on the Hofstede classification, it is possible to point to cultural differences between the nations contributing forces to a number of recent multinational operations. They further speculate that the dimensions proposed by Hofstede are particularly relevant to the operation of military forces '…..in hierarchical organisations such as armies, power distance (the respect and deference given by subordinates to superiors) may influence many aspects of relationships'….such as….'the interpretations of superiors' commands and the legitimacy of challenging them'. This issue is returned to later in the paper.

Communication

Perhaps the issue that is raised most frequently in relation to multinational co-operation is language. Communication is the cornerstone of effective teamwork. A clear challenge to effective communication in multinational forces relates to spoken and written language. Effective communication involves more than just the giving of information or instructions. McIntyre and Salas (1995) stress that in order to communicate effectively, the 'sender' should ensure that his or her message is received in full and understood by the intended 'receiver'. In order for this to occur, the receiver should demonstrate to the sender whether the message has or has not been understood. These principles are true of all communications, including face to face conversation, telephone calls, e-mails, and letters. McIntyre and Salas refer to this process as 'closed loop communication'.

In cross-cultural interactions, where those conversing have different mother tongues, it is essential that great care is taken by both participants to ensure that mutual understanding is achieved. Clearly, one, or both, parties must interact in a second language. As Smith and Bond (1998) point out, this can place 'considerable cognitive strain on the second-language user who may already be contending with heavy demands in dealing with the task that brought the parties together in the first place'. Moreover, as Palin (1995) stresses, 'as important as the ability to converse colloquially with military partners on a day-to-day basis is the need to be able to speak a military-technical language and to appreciate the military message implicit in an instruction or order'. Thus, Palin suggests that there is a clear need for partners to develop and learn a shared technical language. This issue was also raised during interviews with British officers with experience of working in multinational forces (Verrall and Stewart, 2000).

Smith and Bond stress that cross-language encounters can also place unusual demands on those conversing in their mother tongue since they must be able to read non-verbal confusion signals given out by the person they are interacting with. Such signals can include 'embarrassed laughter, nodding, furrowing of the brow, slackening of the jaw, and verbal utterances'. The important point to note is that, non-verbal behaviour can also vary between cultures. It is important for individuals to realise that, although they are using the same spoken language, the non-verbal behaviour they exhibit may be unusual and difficult for their partner to interpret.

Mills and his colleagues at CHS Fort Halstead emphasise that sharing information amongst team members does not ensure shared understanding (Mills, Pascual, Blendell, Molloy, and Verrall, 1999). They suggest that information recipients should be asked to demonstrate understanding by providing a précis in their own words. Palin stresses that, as the range of nations that might contribute to multinational operations increases, potential vulnerabilities relating to language use also increase. He points out that, although, where possible, such problems are anticipated by the adoption of standard operating languages, as is the case in the NATO alliance, it is also quite possible that future multinational operations will require the formation of ad hoc coalitions. Palin suggests that, since participation in such operations could be at a relatively low level, for example the contribution of battalion or brigade sized formations to peace support operations, this implies that there is a requirement for second-language ability at those organisational levels.

Palin proposes procedural solutions to enhance effectiveness in such situations, for example 'planning the employment of units with linguistic compatibility in adjacent sectors…..and avoiding the employment of units with no linguistic understanding together on types of operations that require close liaison….in short, in the new multinational environment military personnel need to be proficient in languages to a greater degree than hitherto…and each nation should have a cadre of multilingual military interpreters and liaison officers integral to its manpower structure'. Indeed, effective co-operation will rely on liaison officers in multinational force HQ and subordinate HQs, ensuring 'closeness of fit' between the commander's understanding of a plan and subordinate commanders' understanding of it.

Inevitably, these essential co-ordinating activities will also introduce time pressure penalties and may cause a slowing of tempo. The only acceptable outcome of communication, whether it is designed to share information or provide a specific tasking, is the establishment of a shared understanding. This can be difficult at the best of times let alone in a stressful operational environment. As we have seen, the requirement for partners to communicate, where one, or both, are using a second language introduces new challenges, and consequently new vulnerabilities. Effective communication is fragile and can be undermined by misinterpretation of colloquial language, technical language, and non-verbal cues.

Organisational culture

It is important to remember that multinational forces imply interactions between representatives from different organisational as well as national cultures. Recent interview studies involving British officers with experience of multinational forces raised a number of issues relating to cultural differences between organisations (Mills et al., 1999, Verrall and Stewart, 2000). For example, subtle differences in decision making were discussed. Mills et al. quote a British Major who was put in joint command of a team with a Major from a partner nation. ' I found myself making a few too many assumptions……I was ready to go on decisions, but I would see him going up the chain for nearly everything. At first I couldn't understand this because we were the same rank. Eventually we came to some compromise'. Similar points were raised, independently, by more than one interviewee. It is important to note that the interviewees were not suggesting that their approach was in any way superior to that of the partner organisations involved. Rather, they were surprised that they could not always rely upon expectations and understandings that they had built up over the course of their own careers and had never had cause to question previously.

One officer interviewed by Verrall and Stewart pointed out that relations between the ranks may differ in terms of formality between different nation's militaries. For this reason, he explained that he was aware that he could not simply apply the model that he had learned in Britain just in case he inadvertently caused offence, for example through over-familiarity. As was alluded to earlier in the paper, in Hofstede's terms this concern relates to differences in 'power distance' between the organisations concerned.

These simple examples suggest that new members of a multinational organisation, for example a multinational force HQ, must quickly learn and conform to the emergent culture of that hybrid organisation. Commentators such as Elron et al. (1999) have emphasised that the effectiveness of multinational forces can be enhanced through opportunities for combined training and exercises. Moreover, such training can provide valuable experience of the challenges of working in MNF that individuals can take to any future multinational environment, even an ad hoc coalition.

Anecdotal evidence from interviews conducted by Verrall and Stewart (2000) reinforces the view that it is useful for individuals to gain experience before being posted to a multinational organisation. Experience gained in an exchange post, for example as a defence attaché, was deemed to be valuable. Some suggestions were also made as to the ways in which individuals might be prepared for such postings. Multinational cultural awareness training, such as is provided for business executives who are to take up a foreign posting, was suggested as one option. It was noted, however, that this type of training is generally aimed at preparing an individual for interacting with only one specific culture, not a range of cultures.

A suggestion that was raised more than once in the CHS interview studies with British officers, was that it would be helpful for members of a multinational team to keep a diary to pass on to their replacements at the end of their tour. It was suggested that at the very least, this would provide some useful advice on what to pack! More importantly, it would allow 'lessons learned' to be passed on to ease the replacement's integration into an established team. In view of the fact that personnel turnover is rapid in multinational organisations, (Elron et al., Mills et al) it is very important that replacements are able to integrate rapidly into the team.

Culture and technology

An initial search of the literature relating to multinational forces suggests that despite the increased reliance on technology in modern military systems, little research has been conducted into differences between nations in their use of such systems. Some research in this area has been conducted in the field of aviation psychology. Work has been conducted by Bob Helmreich and his colleagues at the University of Texas into the influence of national culture on airline pilots' attitudes to cockpit automation (Sherman, Helmreich, & Merrit, in press). In modern jet airliners, pilots are given considerable discretion as to when and how to employ the available automation. Helmreich states that few organisations have defined the way in which automation should be used. The results of their survey of 6000 pilots indicated that, in terms of Hofstede's classification, those from cultures characterised by high power distance were more positive about automation, and more likely to use it under all circumstances. They concluded that 'willingness to interact with the' flight management 'computer, and use it as a discretionary tool, is a pattern more consistent with individualistic, egalitarian-based societies which favor flattened command structures……while pilots from more hierarchical national cultures may be more inclined to accept the FMC's authority without question'. Attention has rightly been given to the question of compatibility between systems as modern militaries move towards a CIS-mediated mode of operation. Drawing a general point from Helmreich's findings might lead us to suggest that, at the design stage, consideration should be given to the issue of the way in which personnel from diverse organisational and national cultures might interact with modern technological systems.

Concluding remarks

As was stressed at the outset, this paper has not set out to provide an exhaustive discussion of the influence of culture on multinational forces. Rather its purpose has been to provide a flavour of the types of cultural factors that appear to raise challenges to optimum multinational inter-working. More needs to be done in the future to identify such vulnerabilities and to attempt to neutralise them through practical countermeasures. Such countermeasures are likely to include interventions such as appropriate selection and training of personnel for multinational postings, improved workspace design and technological support, and improved procedures for multinational interworking.

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"The Development of Web-Based Assessment for Tri-Service Selection: A Series of Questions?"

K J Weston
DERA Centre for Human Sciences
Room 1011, Building A50
DERA Farnborough
Ively Road, Farnborough
Hampshire, GU14 0LX
United Kingdom

Summary
From work funded by the MoD, Corporate Research Programme, we have reached the stage of examining the Internet as a means of selection for the Armed Forces. Previous work has looked at computer-based testing, adaptive testing and the introduction of common tri-service selection. Currently the UK Armed Forces share physical locations and some processes in their recruitment but each has its own selection test. One potential future is to form a tri-service selection system, including a management information system and web-based assessment. The potential of the Internet is already being exploited by the Services for marketing purposes, but has greater potential still. Already, the Armed Forces and other organisations are using web-sites to advertise positions and recruit personnel. This is creating competition for the potential candidates for the Armed Forces. There is potential to expand the use of the Internet to streamline the recruiting and selection processes. This paper raises some of the many questions that require answers before we can leap into this brave new world.

Where are we now?
The UK Armed Forces currently use three selection tests for their recruitment. The Royal Navy use Recruiting Tests (RT), the Royal Air Force use Airman Selection Tests (AST) and the Army use British Army Recruiting Battery (BARB). All these tests are for gate-entry level and are broadly measuring general intelligence. Meanwhile, other aspects of the selection and assessment system have been brought together, such as the physical location of recruitment offices. In addition, the Services are moving towards a common management information system.

There is the potential for a new common computer-based test or tests for initial selection to be developed for all three Services and integrated with the common management system. Indeed, adopting a common administrative process as well as a common tri-service test could make large cost savings, (Dukalskis et al, 2001). The Internet may provide a way of exploiting any new system to its full potential.

Is there a brave new world ready to be exploited?
There is no doubt that web-based technology is still a fast growing arena. Within the UK, 7.8 million households had access to the Internet last year (CyberAtlas, 2001). This is more than three times the number of households that had access in 1998. World-wide, the Computer Industry Almanac has forecast that nearly 8% of the population (490 million people) will have access to the Internet in 2002 (CyberAtlas, 1999).

Within recruitment, the Electronic Recruiting index (ERI, 2000) has shown an increase in the amount spent on recruiting over the Internet from $4.5 billion in 1998 to $15 billion in 1999. The advantage of using the Internet for the organisation is the 'free' assessment time and limited costs involved. The potential candidate spends their own time online and very little resources of the organisation are required.

So what could we include in web-based assessment?
We can use a web-site on the Internet for any of the following and this is not an exhaustive list:
1. Providing careers information
2. Pre-screening
3. Applications
4. Psychometric Selection testing

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5. Interviews
6. Assessment centres
7. Reference checks (medical, criminal and credit checks).

There are many strengths and weaknesses for using these different activities. The issues are generally not technical. Areas such as interviewing by video-conferencing are a reality. The technology exists to deliver selection tests and it is relatively straightforward. We are theoretically strong in some areas, including item generation, item response theory and computer-based testing. In addition, computers open the way to many new types of items, for example using dynamic items and adaptive tests, and tests that can measure both accuracy and response latency (Bartram, 1999). However, very few recruiters currently use online selection (Baron et al, 2000).

One possible image of the future?

A potential candidate may be surfing the web one night. He or she will come across a web-site for the Armed Forces. This site has information on the different roles available in all the services. It has a web-camera on a naval ship, within an aircraft hanger and at an Army base (subject to security of course). It provides an interest inventory to help the candidate narrow their search. There is a ‘frequently asked questions’ section and realistic job previews written by serving personnel. The candidate decides they are interested and completes an application form, including a medical questionnaire (that is adaptive) and a biodata form. Automatic screening for eligibility is already underway. The candidate is automatically taken to a page where they book their testing session and any medical screening requirement. The next link provides ample practice opportunities on the selection tests. The tests are computer-based and take them through the gate-entry level on to a series of specialist tests if they meet certain criteria. They can be taken at any local Internet centre where a professional individual can authenticate the candidate’s identification. The candidate goes on to book an interview with the Careers Officer who has all the information available on the Management Information System.

In an ideal world, this process could be seamless. However, before we leap into this fantasy, there are many other practical issues of concern and a large number of questions that require answers.

Will the Internet reach all potential applicants?

Accessibility: We have heard of the Internets growth and that nearly 8 million UK households have access. However, access and actually using the Internet are two very different things. Of visitors to Internet job sites, 70% were employed not currently seeking (monitors); 15% are employed, and thinking about changing jobs (opportunists); and only 15% are actively seeking a new job (active searchers), (ERI,2000). Also, currently the majority of all the job-sites and research is for graduate and professional recruitment. How does this look against the ‘typical’ potential candidate for the Armed Forces?

It has been considered that within 5 years the Internet would be available to all potential applicants (Baron et al, 2000). However, potential candidates are usually young and therefore, more likely to use the Internet, but they may not use it in the context of looking for a career. Is there a difference between those that use it (and the way in which it is used) and those that don’t and will the organisation miss out as a result?

Potential growth: The forecast for Internet access in 2005 will be 11.8% of the world’s population. This is an increase of 4% compared with forecasts for 2002 (CyberAtlas, 1999). However, is this estimated growth too optimistic? We have seen the slow-down of the mobile phone market and the failure of technologies such as e-books that were once viewed as optimistically.

Speed of recruitment: The Internet is likely to make the application process faster. For Army applicants, average wait was found to be around 20 weeks, potentially this could be halved to 10 weeks as CyberAtlas reports an average of 16 days versus 32 days using traditional methods of recruitment (CyberAtlas, 1999). Also, the modal average number of visits to Careers Offices is 5 and is likely that it could be reduced considerably (Hawxwell et al 1997). A recent survey of Royal Navy recruits showed that delays in the recruiting process was one of the reasons most off-putting for potential recruits (Fothergill & Taylor, 2000). This study also showed that females and ethnic minority candidates were more reluctant to approach a careers office directly than their majority counterparts .

Understandable web-sites: Many recruitment web-sites were found to be confusing and badly designed (Baron et al, 2000) and as a consequence were too difficult to use. There needs to be a good understanding of web-based design and formats and how these can be easily used and understood by any potential applicant.

Is the Internet secure and confidential?
Much of the technology for transmitting data across the Internet is actually more secure than many other forms of communication. However, the belief that the systems are secure is not there. This belief in security and confidentiality is especially crucial when reference checks are required, such as medical and criminal screening. Also, the idea of all this information being available through the Management Information System could be viewed with scepticism. In the UK, the Data Protection Act must be followed and again, best practice should be identified.

Is the actual applicant the one who is completing the process?
Authentication: Ensuring the applicant is the one who is completing the process is especially critical when it comes to selection testing. One option is to use remote testing stations with an administrator or some professional whom could authenticate the candidate's identity. However, this limits some of the advantages of web-based recruitment, such as the candidate not having to travel.

But, a question not answered is would individuals' cheat? There is little evidence on this. Although technology such as fingerprints or retinal scans are feasible, there may not be any need to resort to this technology. Perhaps a methodology could be for the candidate to sit the tests at their chosen location and then validate results by administering a parallel form of the same tests to a random percentage. An alternative would be to use tests and measures that are less prone to cheating. For example, measures where it is in the candidate's interest to be honest, or where it is difficult to determine what the correct response might be, e.g. biodata forms and interest inventories.

How can the process be administered fairly?

For selection tests: Internet access is available at home, school, work, Internet centres, and Internet cafes. How will these provide standardised conditions for testing purposes? What will become of formal training in the administration and interpretation of selection tests? The computer will be relied upon very heavily (creating a black box) to provide the fair administration and feedback on assessment tools.

Practice: Practice is required on selection tests to ensure a level playing field for all the candidates prior to testing. The Internet could be used for this but it depends particularly on the accessibility and hence, we return to the beginning!

Security of Test Materials: The distribution of test materials, freely accessed across the web, also raises questions of test security and the need to safeguard the intellectual property rights of test developers. A lowering of security of test materials could shift the commercial interest away from publishing tests per se to a greater emphasis on test interpretation and models for optimising selection decisions.

What are we doing about this?
The MoD, Corporate Research Programme is funding a project lasting up to three years to examine this area. The programme of work for this year will involve examining the UK Armed Forces needs' and assessment of web-based technology. We are aiming to discover the current research that is available and identify shortfalls, perhaps with a view to develop and trial different selection processes in the future. Initially, we shall be looking at using the Internet for screening potential candidates.

Conclusion
This paper is intended to stimulate debate and organise further research. There is a future for web-based assessment. Many organisations are using the Internet for recruitment purposes already. This is increasing the competition for candidates and has placed the Services alongside international and foreign organisations as well as UK ones. As a consequence, we have not got the time to spend years investigating and answering these questions. However, we are beholden to ensure selection systems are fair and ethical, not only for our

own professionalism, but also to ensure we get the best for our Services. There is a need for research to catch up with the technology. What is necessary is for research to be co-ordinated in this fast moving area.

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Technologies for Supporting Human Cognitive Control

R.M. Taylor
DSTL/ISS Human Sciences
DERA Defence Evaluation Agency
Building A50, Room G007
Farnborough, Hants GU14 OLX
United Kingdom

1. SUMMARY

This paper describes work undertaken to provide a proof-of-concept demonstration of the feasibility of an intelligent aiding system for the fast jet military pilot. The aim was to allow the pilot in control of the aircraft, or the operator in control of an uninhabited air vehicle (UAV) either in the air or on the ground, *"to concentrate his skills towards the relevant critical mission event, at the appropriate time, to the appropriate level"*. The prototype DERA Cognitive Cockpit (COGPIT) achieved this goal with an architecture that coupled on-line monitoring of the operator/pilot's functional state, external environment and mission plan. This derived information for on-line task knowledge management and decision support, and for mediating the timing, saliency and autonomy of the context-sensitive aiding aiding.

2. INTRODUCTION

Historically, the aircraft pilot and cockpit systems have had a master-slave relationship, with full pilot authority for aircraft control functions. This relationship changed with the introduction of computer control technology, with the pilot acquiring systems monitoring and supervisory roles. In the late 1970s, ideas arose for more intelligent cockpit systems, with an interactive and synergistic pilot-system relationship, providing co-operative rather than conflicting advice and control. The crew-adaptive cockpit proposed sensors for monitoring the pilot's state, artificial intelligence (AI) software enabling the computer to learn, and pictorial displays allowing efficient presentation of cockpit information. This developed into a form of 'R2D2' intelligent agent co-operating with the pilot as a Human-Electronic Crewmember (HEC) team, or joint cognitive system. These ideas raise human factors issues of HEC teamwork, adaptive automation, dynamic function allocation and levels of system autonomy and trust, and inferencing pilot intent (Taylor and Reising, 1998; Reising, Taylor and Onken, 1999).

Developments in advanced computer technology now make intelligent pilot aiding realisable, including real-time data acquisition, fusion and processing, and computer modelling and AI inferencing techniques, such as expert systems, knowledge-based systems (KBS) and neural nets. Beginning with the United States Air Force Pilot's Associate (PA) program (1985-1992), expert systems showed the potential of AI to support the pilot's problem analysis and solution generation. In Europe in the 1990s, AI efforts on pilot aiding have centred on the French "Co-pilote Electronique" providing support for pilot situation assessment, and on the German civil and military Cockpit Assistant Systems providing flight management KBS for re-routing. In the United Kingdom, AI research at DERA has focused on KBS for aiding aircrew tactical decisions leading to development of real-time multi-agent KBS software, and new methodologies for knowledge acquisition (KA) and management. Most recently, the US Army's Rotorcraft PA (RPA) has provided a Cognitive Decision Aiding System and Cockpit Information Manager for supporting 2-crew military helicopter missions (Miller, Guerlain and Hannen, 1999).

Related human factors research at DERA has focused on the cognitive engineering issues, associated interfaces and the operation of adaptive automation and decision support (e.g. Taylor, Finnie and Hoy, 1997; Taylor, and Dru Drury, 2001). This is needed to determine the required levels of human control over critical system functions that keep the crew in control of the system, rather than the system in control of the crew. The results highlighted the risks of poor awareness of functioning with dynamically changing automation, and the problems of cognitive bias

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associated with acceptance of uncertain automation advice. This work generally raised concern with the problems of maintaining effective human control of critical decisions and complex system functions with high levels of automation. It identified the need for further cognitive engineering work on cognitive control issues and on supporting adaptiveness. The pilot knowing when and how to change the plan have traditionally provided adaptiveness. Adaptiveness can be considered as the ability of the HEC system to perform in an appropriate, context-sensitive manner in different situations. The nature of the knowledge underlying the task adaptation is key. Ideally decision aiding needs to be adaptive both to individual user characteristics and to changing task situations i.e. using complex task, situation and user knowledge to be responsive to changes in the operating environment, mission requirement and operator capability. Furthermore, adaptive aiding needs to respond to context divisions with sensitivity that is both precise and accurate, i.e. supports handling of critical events, in the appropriate manner and at the appropriate time. This increased adaptiveness needs to be achieved without increasing crew workload and without the unpredictability often associated with the action of conventional automation (Miller and Goldman, 1999). It is believed that this could be achieved through cognitive co-operation afforded by context-sensitive HEC teamwork, based on shared understanding of mission goals and tasks. But cognitive co-operation brings increased risks arising from communication, as illustrated in Figure 1. For this reason, advanced manned interfaces, supporting intuitive interactions and dialogues are likely to be a requirement rather than an enhancement for human-systems effectiveness.

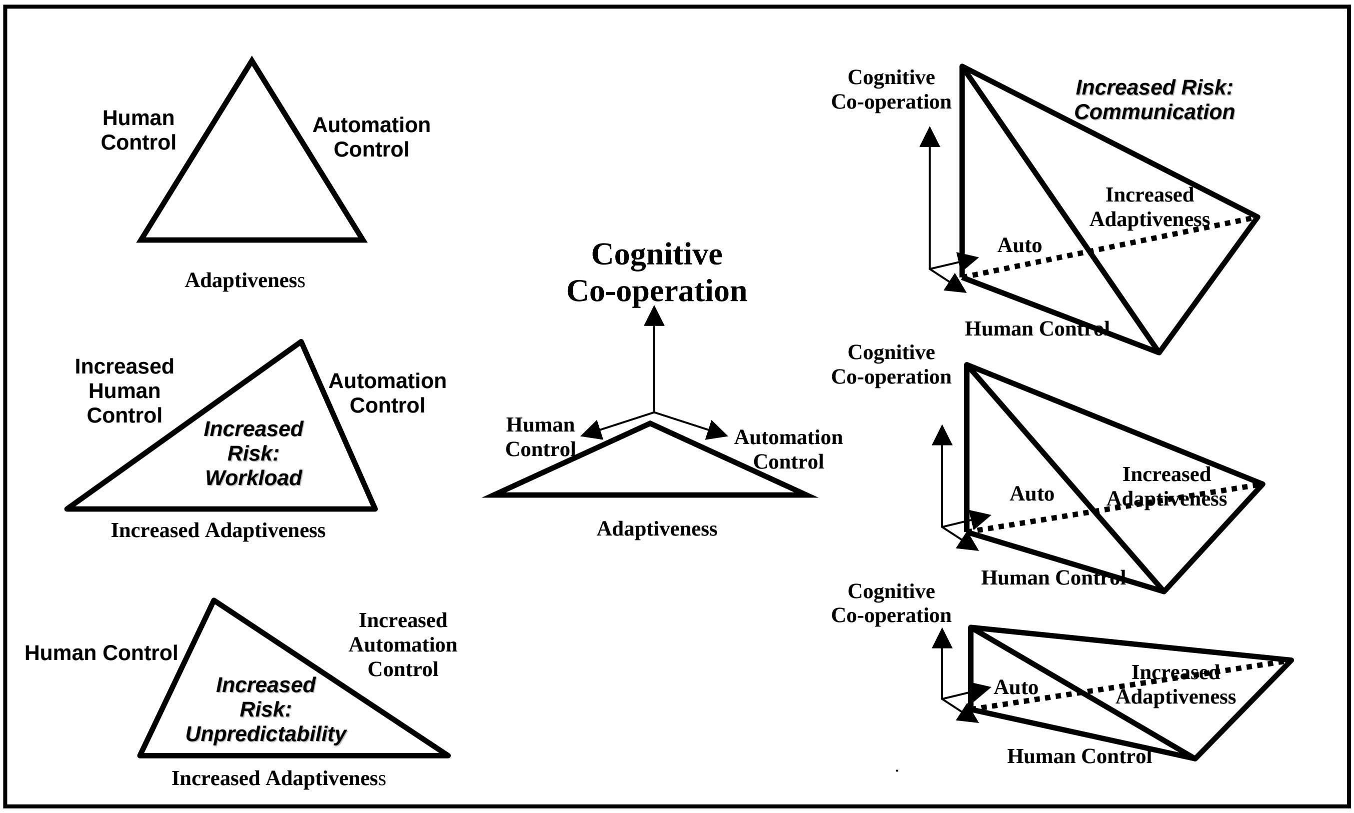


Figure 1. The risks of increasing adaptiveness through increased human control, automation control and through cognitive co-operation.

Currently, intelligent knowledge-based aiding systems are available that are capable of responding to external changes in the aircraft and the environment. Extending this to include the appropriate internal ‘context’ requires a functional architecture with the following attributes (Taylor and Reising 1998):

- A model of human decision making and control abilities,
- The ability to monitor pilot performance and workload through behavioural and physiological indices,

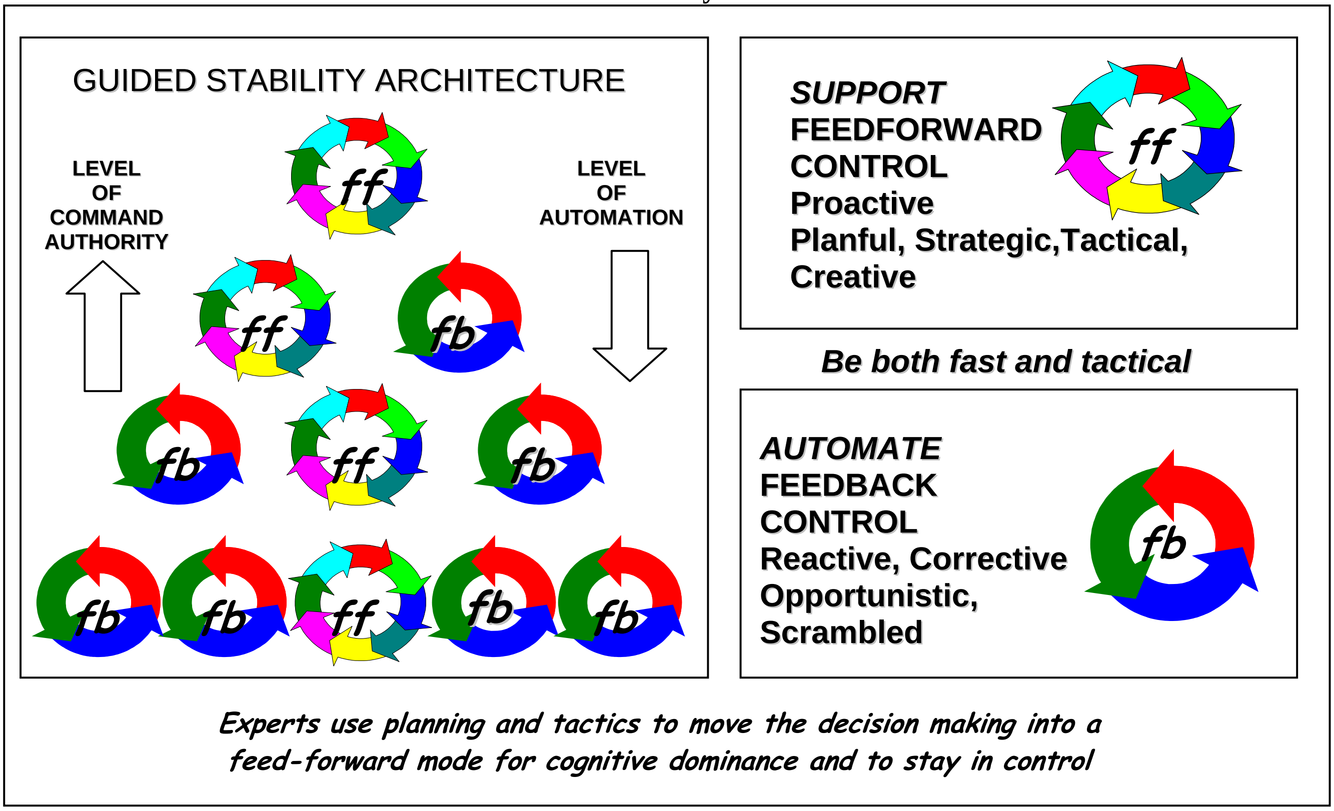
- The ability to predict pilot expectations and intentions with reference to embedded knowledge of mission plans and goals.

These considerations encouraged a more crew-centred approach to cognitive technologies for adaptive automation and KBS decision support, providing ideas for a "*Cognitive Cockpit*" with a focus on cognitive control and adaptiveness issues (Taylor, 1997). In 1998, this led DERA to be tasked by MOD with a 3 year programme of applied research, successfully completed in March 2001, which provided proof-of-concept demonstration of cognitive cockpit technologies for use in future envisioned air systems (Taylor, Howells and Watson, 2000). The aim was to allow the pilot in control of the aircraft, or the operator in control of an uninhabited air vehicle (UAV) either in the air or on the ground, "*to concentrate his skills towards the relevant critical mission event, at the appropriate time, to the appropriate level*". The prototype DERA Cognitive Cockpit (COGPIT) achieved this goal with an architecture that coupled on-line monitoring of the operator/pilot's functional state, external environment and mission plan. This derived information for on-line task knowledge management and decision support, and for mediating the timing, saliency and autonomy of the context-sensitive aiding aiding. It is believed that cognitive power and dominance in combat can be achieved by cognitive control strategies involving feed-forward (proactive, planful, strategic and tactical) and feedback (reactive, corrective, opportunistic and sometimes chaotic) control modes. With both time-pressured decision making and rapidly changing uncertainties, a mix of feedback and feed-forward strategies is needed for guided stability and cognitive combat dominance i.e. being both fast and tactical (Figure 2). The COGPIT project showed that adaptive automation and KBS decision support can achieve this mix by offering automation of difficult feed-back control tasks, where the computer can be both fast and accurate, and by supporting feed-forward control tasks which required decisions to be both creative and tactical. The potential benefits of this high level of human-system integration system include the following:

- Real-time pilot functional state assessment for cockpit task adaptation
- Real-time support for situation assessment, task prioritisation and decision making
- Real-time user-personalised and bespoke cockpit ergonomics
- Real-time safety net, with potential to recover to base an incapacitated pilot.

The greatest challenge in the COGPIT project was for cognitive systems engineering to provide appropriate cognitive automation, interfaces, interaction and dialogues, and to provide appropriate cognitive interventions, and successful performance-shaping aiding and barriers. These should enable cognitive co-operation to operate smoothly and intuitively, without adding to the operator/pilot's cognitive work.

Figure 1. Cognitive control architecture for guided stability with time pressure in uncertainty



3. COGNITIVE DESIGN REQUIREMENTS

Cognitive systems engineering seeks to bring together consideration of the environment, artefacts and agents (human and machine) in a system of systems approach to design (Hollnagel and Woods, 1983; Rasmussen, 1986; Norman 1986). It tries to make sense of the mutual interactions between people and their environments under a variety of changing conditions (McNeese, 1995). This supports a much needed human-centred, rather than technology-centred, approach to systems design, with a strong understanding of the role of artefacts – machines, tools, computers (i.e. things that make us smart or dumb) – of the context of use and of system functional purpose. The need for this approach has arisen generally from human problems of working with automation and computers, and from considerations of human error and safety, in addition to efficiency and productivity. This has led to a focus on analysis of cognitive work and environmental constraints, and ideas such as context of use, cognitive control, situated cognition, and other ecological issues (Hollnagel, 1993; Rasmussen, Pejtersen, and Goodstein, 1994; Vicente, 1999). These ideas and approaches are particularly relevant to the implementation of intelligent aiding systems in complex environments such as military aviation.

In aviation, computer-based cockpit automation has been designed generally to replace rather than to support human functions. Implementation of conventional automation, particularly in civil aviation, has sought to reduce or simplify crew tasks, so as to enable cost savings from reductions in crew complements, human error and training. However, in the military aviation environment, human involvement is needed in systems control to govern the system's functional purpose, and particularly to provide the strategic guidance and tactical flexibility needed in rapidly changing, complex military operations. In the environment of use, the complexity of the military aviation task domains is such that without considerable computerised assistance aircrew would not be able to cope with the very large number of potentially relevant features and a vast number of possible responses. Perceiving and interpreting all of the relevant features and choosing an appropriate response within the tight temporal constraints of the domain will challenge any intelligent agent – whether human or machine. One method of reducing the task

and cognitive load on aircrew, enabling the pilot to concentrate unique cognitive skills on critical tasks, is the provision of intelligent knowledge-based aiding systems with the context sensitivity needed to provide the right information, in the right way, at the right time (Egglestone, 1993). They can provide aircrew with usability aiding - making the crew station easier to use – and mission task aiding – determining when and how to deliver proposals and notifications, and how to offer execution aiding. Significantly, for aviation, the introduction of intelligent aiding systems requires cockpit systems engineering to consider the cognitive requirements in the specification and design of cockpit processes, in addition to the basic system physical design (Egglestone, 1993; Taylor, MacLeod and Haugh, 1995). Egglestone re-defines cognitive design requirements as "*all the system factors that are essential for it to behave at a conceptual (symbolic and abstract) level of understanding and engage in a knowledge level discourse with the user*". He notes that conventional cockpits, aimed at providing information delivery and a control system, have cognitive requirements imbedded in their basic design, captured through mission, task, information and workload analyses. In contrast, intelligent cockpits aimed at mission task and usability aiding, through inter-agent, knowledge-based, conceptual, mixed initiative transactions, have the additional cognitive design requirements of the design of the knowledge base and reasoning processes that need to be embedded in the system process architecture.

Validated psychological methods and techniques are needed to capture cognitive requirements of the essential high level internal processes of users' mental models. The methods available for cognitive systems engineering are becoming increasingly diverse and mature, and available for use as a systematic practice, such as the Work Domain Analysis (WDA) Workbench (Sanderson et al, 1999). They include the following:

- cognitive modelling,
- cognitive work analysis (CWA),
- functional decomposition,
- cognitive task analysis (CTA),
- control task analysis,
- concept mapping,
- knowledge acquisition (KA),
- knowledge modelling,
- ecological interface design (EID) and
- prototype story boarding.

A key development underpinning the DERA COGPIT project has been the use of CommonKADS knowledge engineering methodology for the design of KBS (Shadbolt et al, 2000). This provides a model-based approach that focuses on the knowledge issues of acquisition, modelling and reuse and maintenance. It distinguishes the aiding context in terms of the requirements of the organisation, tasks and agents. Specific knowledge-level models for development prior to the implementation of a KBS are identified:

- Organisational model: organisational analysis to identify the opportunities for knowledge-intensive systems within it
- Task model: identification of the major tasks involved within the organisation
- Agent model: modelling of the agents (humans, information systems and other entities) that carry out tasks within the organisation
- Knowledge model: an implementation-independent description of the knowledge components involved in carrying out a task
- Communication model: description of interactions between various agents involved in a task
- Design model: a technical system specification that indicates how the knowledge model and communication model will be implemented within a specific environment

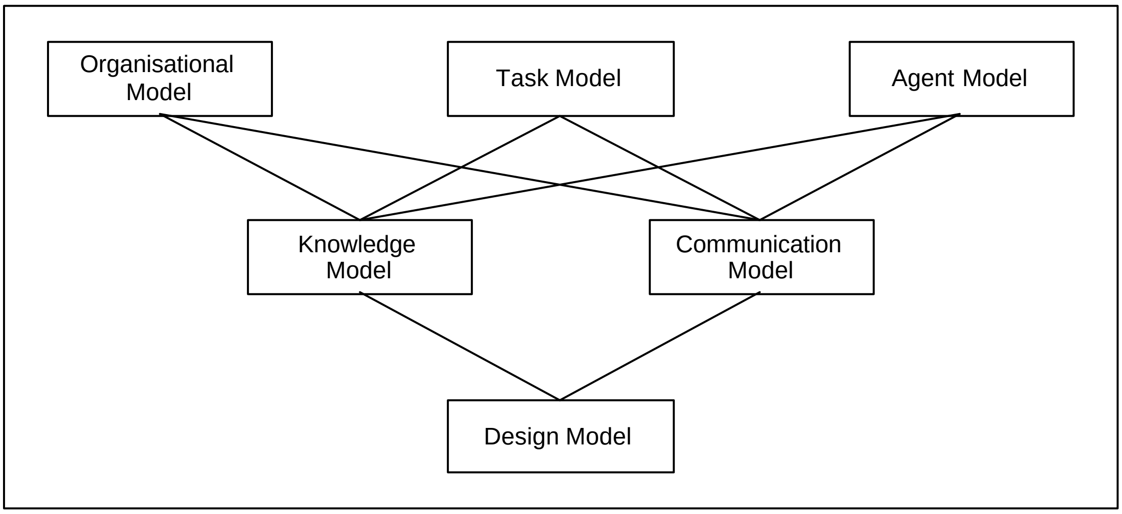


Figure 3. The CommonKADS models

The organisational, task and agent models provide information for the knowledge and communication models, which themselves provide information for the design model (Figure 3). Organisational, task and agent models concern the aiding context. Knowledge and communication models concern the system concept. The design model concerns the artefact. For KBS, the models are implemented according to structure-preserving design principles so that the implemented code retains the organisation and structure of the antecedent models. Conventional cockpit design processes focus on the task, communication (human-machine interaction) and interface design requirements.

Three principle agents with different tasks can be distinguished that comprised the COGPIT system as illustrated in Figure 4:

Cognition Monitor (COGMON) was responsible for monitoring the pilot's physiology and behaviour to provide an estimation of the pilot's functional state. This module was concerned with on-line analysis of the psychological, physiological and behavioural state of the pilot. Primary system functions include continuous monitoring of workload, and inferences about current attentional focus, ongoing cognition and intentions. It also sought to detect dangerously high and low levels of arousal. Overall, this system provided information about the objective and subjective state of the pilot within a mission context. This information was used in order to optimise pilot performance and safety, and provided an on-line cognitive basis for the implementation of pilot aiding (Pleydell-Pearce et al, 2000).

Situation Assessor Support System (SASS) was responsible for monitoring the aircraft situation and outside environment and recommends actions. This module was concerned with on-line mission analysis, aiding and support provided by real-time, multi-agent KBS software. This system was privy to the current mission, aircraft (e.g. heading, altitude and threat) and environmental status, and was also invested with extensive *a priori* tactical, operational and situational knowledge. Overall, this system provided information about the objective state of the aircraft within a mission context, and used extensive KBS to aid and support pilot decisions (Shadbolt et al, 2000).

Task Interface Manager (TIM) was responsible for monitoring the mission plan, deciding automation and managing the cockpit interface. This module was concerned with on-line analysis of higher-order outputs from COGMON and SASS, and other aircraft systems. A central function for this system was maximisation of the goodness of fit between aircraft status, 'pilot-state' and tactical assessments provided by the SASS. These integrative functions enabled this system to influence the prioritisation of tasks and, at a logical level, to determine the means by which pilot information was communicated. Overall, this system allowed the pilots to manage their interaction with the cockpit automation, by context-

sensitive control over the allocation of tasks to the automated systems (Bonner, Taylor and Miller, 2000).

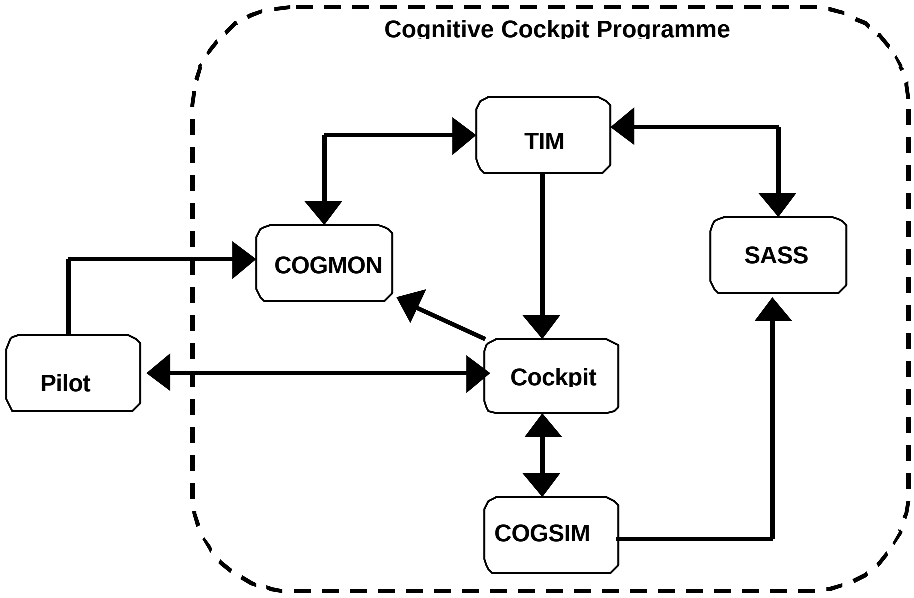


Figure 4. COGPIT Agents Architecture

Support to the pilot from COGMON and SASS was managed through the TIM and the associated cockpit interfaces. For the purposes of demonstration, test and evaluation, these sub-systems operated within a COGPIT simulation environment (COGSIM). COGSIM was concerned with the specification and provision of a proof-of-concept, technical demonstrator, simulation test environment for pilot aiding. A simplified representation of the processes performed by these agents, in support of updating the mission plan, is shown in Figure 5.

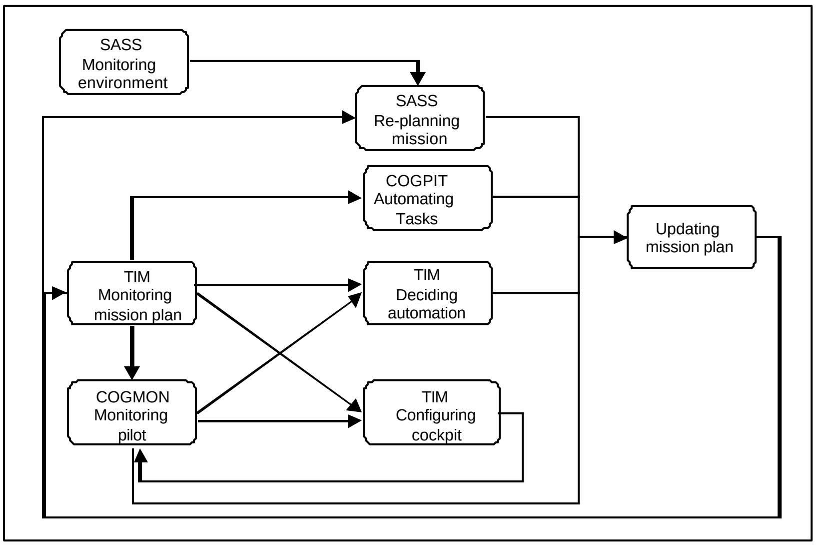


Figure 5. COGPIT Agents, Processes and Tasks

The aim of the COGPIT architecture was to increase system adaptiveness by enabling changes to be made to the mission plan in response to changes in the situation. The COGPIT monitored three aspects of the situation: *the pilot* to take account of his physiological and cognitive state; *the environment*, both external to the aircraft and the aircraft systems; and *the mission plan* to indicate current and future pilot actions. Information from monitoring the environment, the mission plan and the pilot provided inputs into the processes of re-planning the mission, automating tasks, deciding automation and configuring the cockpit. These processes then provided inputs into updating the mission plan.

4. MODEL REQUIREMENTS

The development of the CommonKADS models for the SASS utilised a number of KA techniques, including structured interviews, laddering, repertory grid analysis, card sorts and questions. The KA was conducted in parallel with knowledge modelling, in consultation with subject matter experts (SME), which improves the validity of the models. The PC PACK and MetaPACK toolsets, developed by Epistemics Ltd, were essential in supporting the acquisition and modelling processes. The results of the KA provided knowledge documents giving implementation-independent models of the knowledge involved in the relevant tasks.

The development of the COGMON used a real-time multi-dimensional model of cognitive-affective state. Information was derived from a wide range of physiological, behavioural, subjective and contextual variables. Multiple measures were combined, using convergent processing and multi-variate analysis, to draw higher level state inferences, such as alertness, stress, physical and mental demand, and current locus of attention and intent. These inferences were based on a model of brain organisation that identifies modality specific processing entities (visual, auditory, somatosensory, motor), and a distributed higher order processing network. Performance is limited by competition for common cognitive structures. Refinement of the model and information requirements was by extensive laboratory empirical test and validation using representative operator tasks. Predictable regularities in responses in individuals were learnt and provided a bespoke monitoring system with impressive diagnostic and predictive power.

The main features of the TIM functioning were a shared mental model of the task, the ability to track goals, plans and tasks, and the ability to communicate intent about the mission plan. The task model used a taxonomy derived from mission descriptions and information requirements analysis. The task model needed to be representative of the way pilots think of their work domain with operator-based labelling conventions, and provided alternative methods to achieve each task or goal. KA sessions used structured interviews, laddering and verbal protocols based on the Goals, Means Task Analysis methodology. Three task categories were used: generic tasks that were constant for a particular task for any mission, mission specific tasks that were constant for a particular task within a particular mission and specific tasks that differed for each instance of a particular task.

5. TASKING INTERFACES

The idea of a tasking interface exploited the lessons learnt from the US Army's RPA program (Miller, Guerlain and Hannen, 1999). It arose from the need to be able to predict pilot expectations and intentions with reference to embedded knowledge of mission plans and goals. The aim was to provide an adaptive or "tasking" interface that allowed the operators/pilots to pose a task for automation in the same way that they would task another skilled crewmember. It afforded operators/pilots the ability to retain executive control of tasks whilst delegating their execution to the automation. A tasking interface necessitated the development of a cockpit interface that allowed the pilot to change the level of automation in accordance with mission situation, operator/pilot requirements and/or operator/pilot capabilities. It was necessary that both the operator/pilot and the system operated from a shared task model, affording communication of tasking instructions in the form of desired goals, tasks, partial plans or constraints that were in accord with the task structures defined in the shared task model.

Allowing operators/pilots to choose various levels of interaction for the tasks they are required to conduct can mitigate the problem of unpredictability of automation. TIM utilised the monitoring and analysis of the mission tasks provided by the SASS combined with the pilot state monitoring of the COGMON to afford adaptive automation, adaptive information presentation and task and timeline management. The overall architecture of an adaptive cockpit involved the functions and flow of information and control illustrated in Figure 6**.**

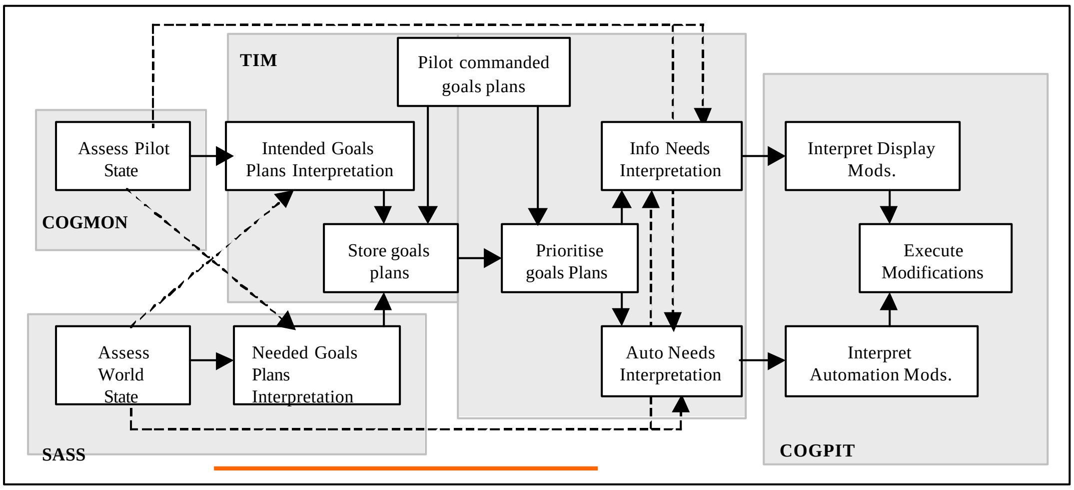


Figure 6. Flow of information across functions

The COGPIT work included mission-based functional decomposition, cognitive task analyses, knowledge acquisition and modelling, interface prototyping, proof-of-concept simulation, cognitive story-board evaluation, control task analysis and risk analysis. Requirement analyses were based on assumptions concerning future capabilities and technical developments, which required SMEs to extrapolate from their knowledge base. This posed considerable problems in validation. A particularly difficult area was the analysis of cognitive requirements of future automation capabilities. 'Heads-up' methods of interaction exploiting helmet-mounted displays (HMD) and direct voice input/output (DVI/O) were strongly favoured. A baseline conventional 'EF22' cockpit, and a candidate COGPIT with TIM interfaces, were built for comparative evaluation using a scripted offensive air scenario. The idea that the scenario should be sufficiently difficult to defeat the baseline cockpit was an important scenario and candidate COGPIT design driver. The validity of the scenario and the missions needed to be checked and maintained to ensure the validity of the findings for the intended, platform specific application. However, the basic aiding concepts and technologies are likely to be generalisable to other applications and domains. A function-based system for measures of effectiveness (F-MOEs), based on the task taxonomy, was developed to provide information on mission confidence for on-line pilot feedback, and for analysis of the benefits of aiding options.

The key development was the system for pilot authorising and control of tasks (PACT) to levels of automation with TIM support. The PACT system described in Table 1 has broad applicability to all future systems requiring operator control of levels of system autonomy. The system uses military terminology to distinguish realistic operational relationships for five aiding levels, with progressive operator/pilot authority and computer autonomy supporting situation assessment, decision making and action. This progression of authority and autonomy in relation to the observe-orient-decision-action OODA loop is illustrated in Figure 7. The PACT terminology and selection of levels are based on operational considerations to afford usability and compatibility with military user cognitive schemata and models. The PACT system provides a logical, practical set of levels of automation, ranging from fully manual, assisted, to fully automatic modes, with four levels of automation assistance, which can be, changed adaptively or by pilot command. Figure 8 illustrates the strategy for management of performance variability triggered by inputs from COGMON and SASS, showing links between the PACT levels, cognitive intervention and the saliency of TIM cockpit messages. The four assisted levels provide progressive support of pilot situation assessment, decision and action. These are a reduced set of levels, with clear engineering and interface consequences, derived from levels of automation for human-computer decision-making proposed previously. Borrowing an aircrew term from co-operative air defence, the idea is that the pilot forms a *contract*, or set of contracts, with the automation using the PACT system by allocating tasks to PACT modes and levels of automation aiding. The contract defines and constrains the nature of the operational relationship between the pilot and the computer aiding during co-operative performance of functions and tasks. Table 1 provides a description of the method of control of PACT levels by pilot command using Direct Voice Input (DVI).

Mission functions and tasks, at different levels of abstraction allocated individually or grouped in related scripts or plays, can be set to these levels in a number of ways:

- Pre-set operator preferred defaults,
- Operator selection during pre-flight planning,
- Changed by the operator during in-flight re-planning, probably using DVI commands,
- Automatically changed according to operator agreed, context-sensitive adaptive rules.

The PACT system is designed to support the pilot's cognitive work. The support ranges from providing advice to providing action. The cognitive work required can be represented in terms a perception-assessment-decision-action (PADA) decision ladder. Control task analysis (Vicente 1999) has been used to identify the structure of the cognitive work performed by the operator/ pilot and by automation at each PACT level. Figure 9 provides an example of the control task analysis for PACT Level 3 Assisted-In Support, expressed in PADA decision ladder terms. On the basis of control task analyses for each PACT level, estimates of the resultant or residual cognitive load for the operator/pilot can be identified for different degrees of operator/pilot critical involvement (immediate acceptance, critical acceptance, independent analysis). A simplified characterisation of the levels of PADA cognitive work for Automatic, Assisted and Commanded PACT levels is illustrated in Figure 10. Figure 10 also a summary of the SME identified risks associated with Automatic and Commanded PACT levels, and the mitigation provided by the Assisted PACT levels.

6. CONCLUSIONS

The final customer milestone demonstration of the integrated COGPIT system took place at DERA CHS in March 2001. It was deemed highly successful by the military customer. With the increased interest in UAVs and Unmanned Combat Air Vehicles (UCAVs), future manned aircraft procurements now seem likely to be based on incremental upgrades of existing systems, with evolutionary rather than revolutionary cockpit systems. It appears there may be no immediate requirement for a fully functional Cognitive Cockpit with adaptation to pilot functional state. However, for future air systems with a mix of manned and unmanned platforms, it seems likely that advanced adaptive interface technologies, such as the TIM and PACT systems, will be a requirement operator/pilot control of multiple UAV/UCAVs.

The COGPIT project has exercised a wide range of cognitive engineering methods and cognitive technologies for intelligent knowledge-based pilot aiding. These are listed in Table 2. These cognitive technologies include pilot functional state monitoring – in its infancy in providing on-line measurement and interpretation for task adaptation – and task knowledge management and decision support for context sensitive aiding – applying relatively mature knowledge engineering techniques to support adaptiveness in real time. This system has been shown to be capable of recognising the need for automation in order to achieve a mission objective, and of providing timely instructions to the operator/pilot on how to achieve it, and/or implement the required automation where necessary.

Functional analysis of cognitive work provides the essential foundations for the successful development and implementation of cognitive technologies for pilot aiding. The CommonKADS methodology and PC PACK software toolkit for knowledge engineering seems particularly useful for implementing knowledge-based systems. Knowledge engineering methodology can provide useful on-line KBS support for pilot re-planning tasks, and this has the potential for wider application. The traditional KA bottleneck has been significantly reduced by the provision of a structured methodology and tool set. The demonstration highlighted the criticality of the timing of KBS advice in context. The test pilot

The COGMON work indicates that on-line pilot functional state assessment is feasible with current computing power, and looks like providing useful information for cockpit and task adaptation. In particular, the increased power of individual profiles for developing bespoke adaptations seems highly promising. Useful assistance in the management of cockpit interfaces, tasks and automation can be provided by a tasking interface system based on a shared task model. The development of an effective TIM, with which pilots can interact easily, has been critical for

the successful integration and acceptance of the outputs of the COGMON and SASS sub-systems. The technical specification of a tasking interface for this type of system is a major task, particularly as the functional components require iterative development, precluding early definition of inputs and outputs. Although it is relatively easy to track tasks instantiated in a mission plan, it becomes very difficult to track and support tasks that deviate from the intended plan. Tracking deviations requires the system to infer likely pilot intent, which is inherently problematic.

Table 1. PACT System for Pilot Authorisation of Control of Tasks

Primary Levels	Secondary Levels	Operational Relationship	Computer Autonomy	Pilot Authority	DVI
AUTOMATIC		**Automatic**	**Full**	**Interrupt**	**Automatic to Assist**: DVI "Mode XXXX to Assist". **Automatic to Command**: DVI "Mode XXXX to Command"
ASSISTED	4	**Direct Support**	**Advised action unless revoked**	**Revoking action**	**Assisted to Automatic**: DVI "Mode XXXX to Automatic" **Assist to Command**: DVI " Mode XXXX to Command" At any point that the pilot requests a reduction or an increase in automation to assisted automation, the level of assisted automation will default to the pre-defined secondary level of assistance, either 1,2,3 or 4 for that particular task.
	3	**In Support**	**Advice, and if authorised, action**	**Acceptance of advice and authorising action**	
	2	**Advisory**	**Advice**	**Acceptance of advice**	
	1	**At Call**	**Advice only if requested.**	**Full**	
COMMANDED		**Under Command**	**None**	**Full**	**Commanded to Assisted**: DVI "Mode XXXX to Assist". **Commanded to Automatic**: DVI "Mode XXXX to Automatic"

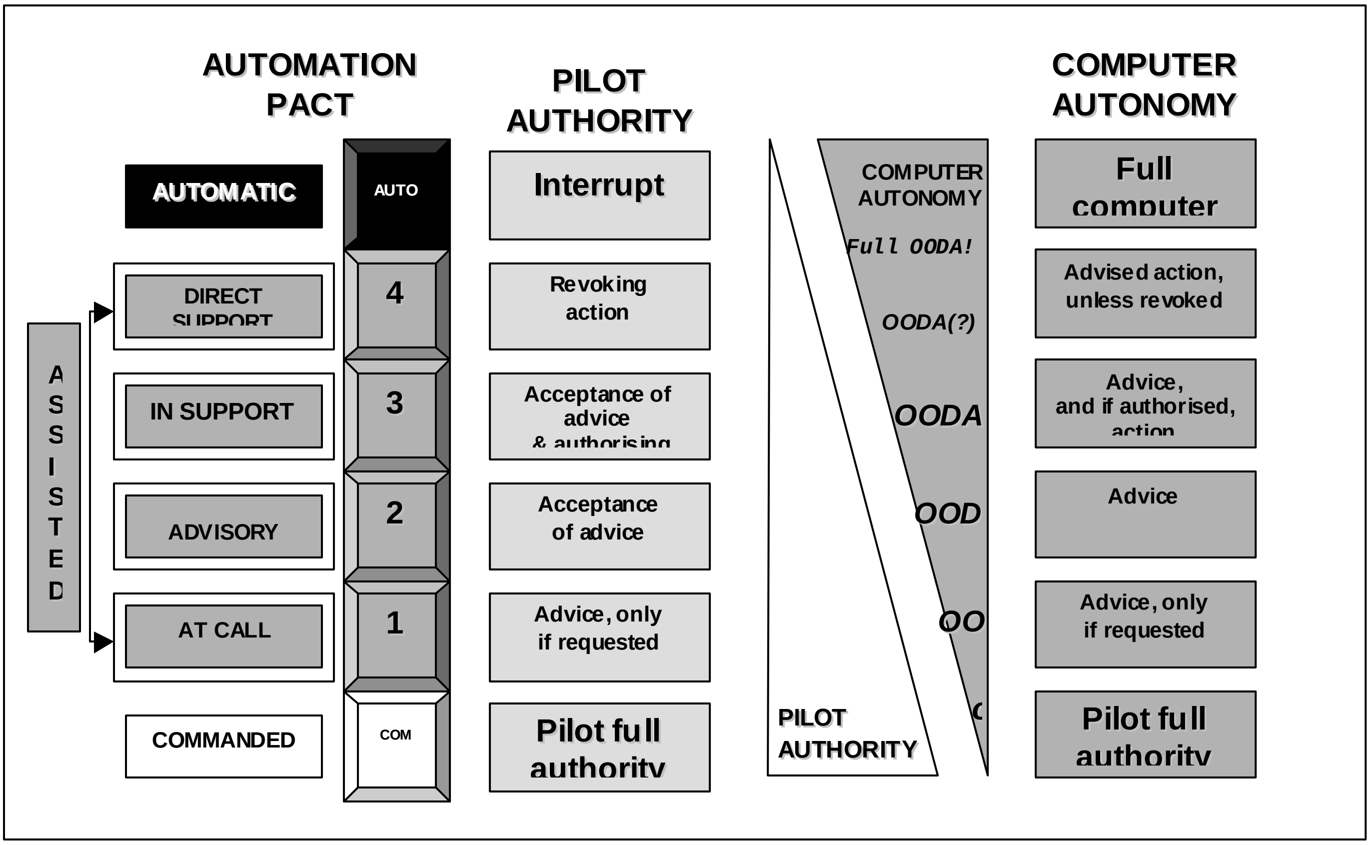


Figure 7. Progression of pilot authority and computer autonomy with the PACT system

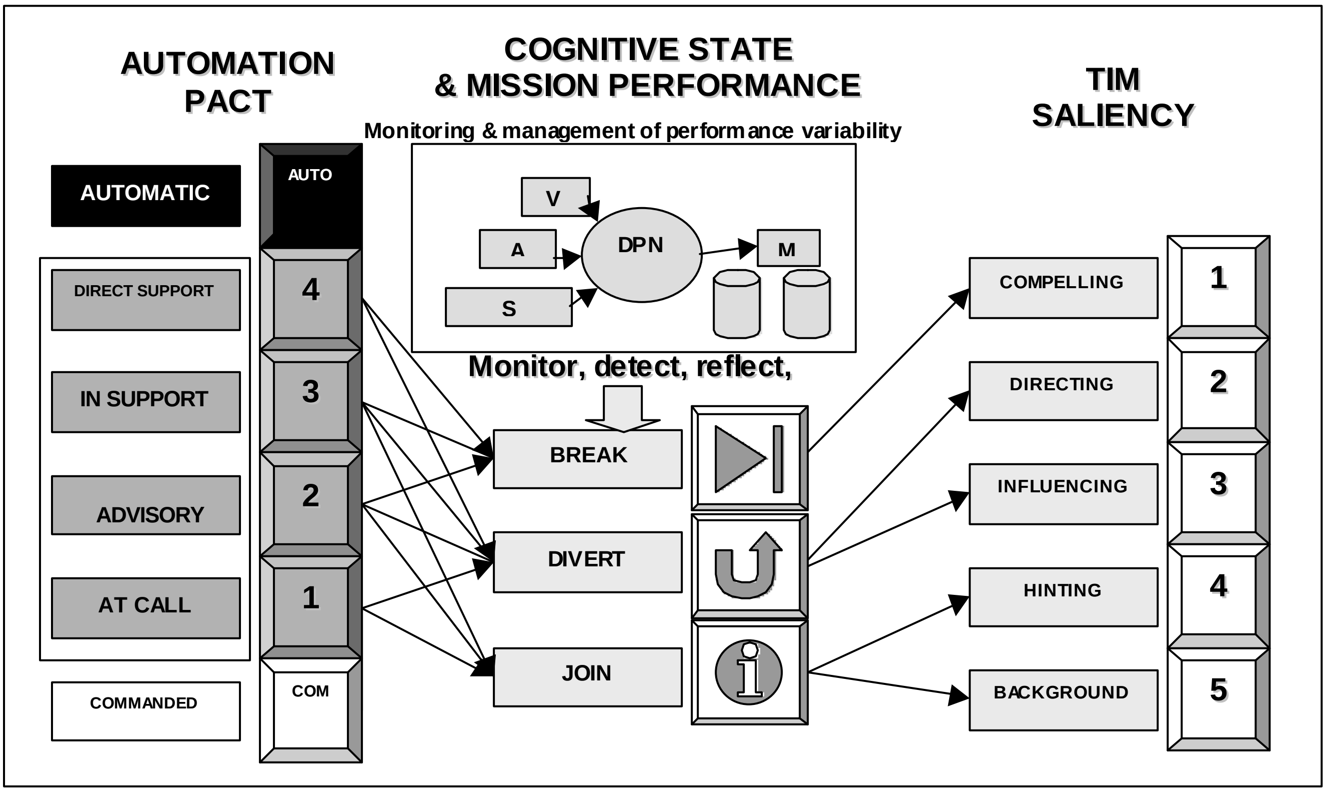


Figure 8. TIM intervention strategy

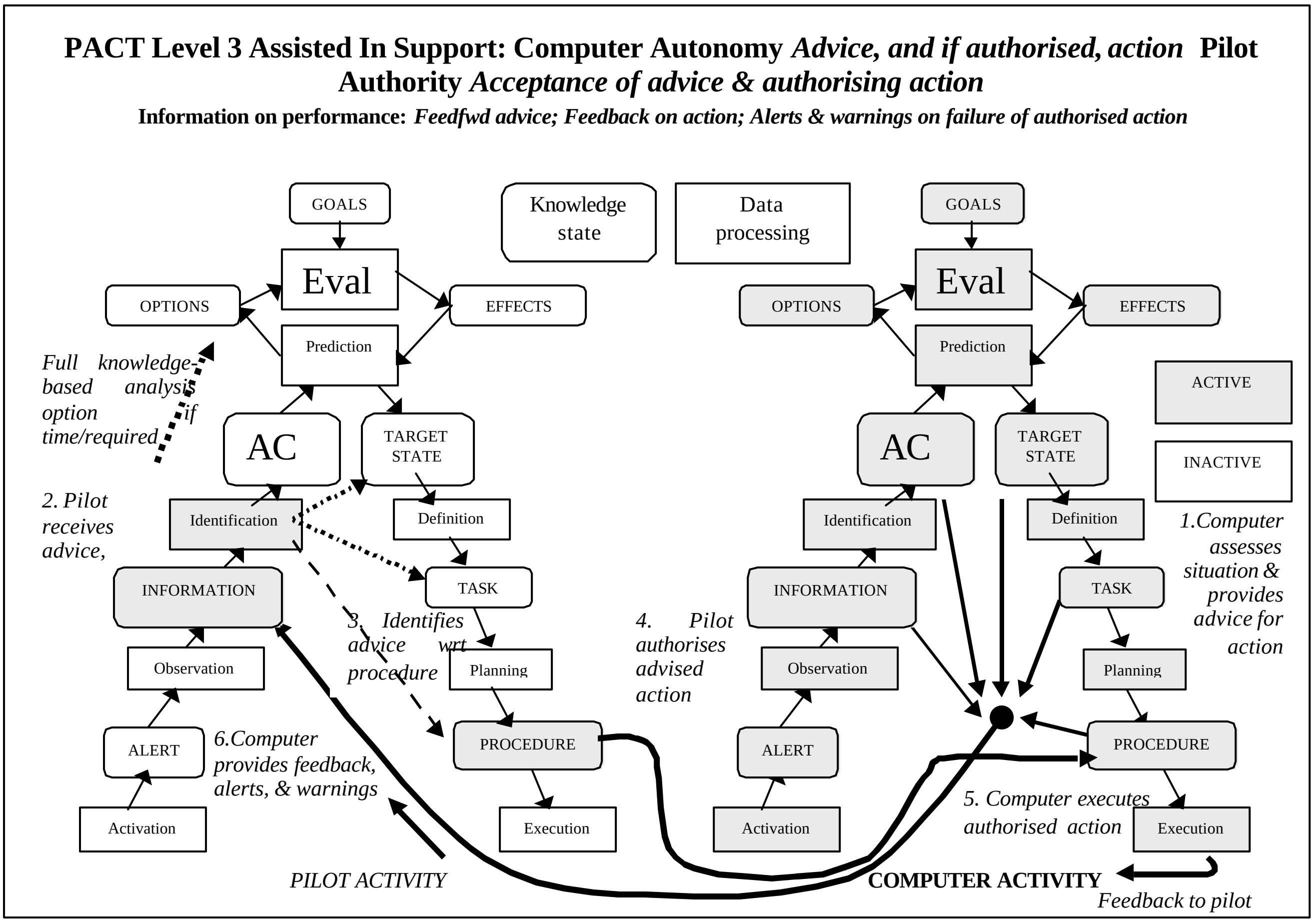


Figure 9. Control task analysis for PACT Level 3 Assisted-In Support

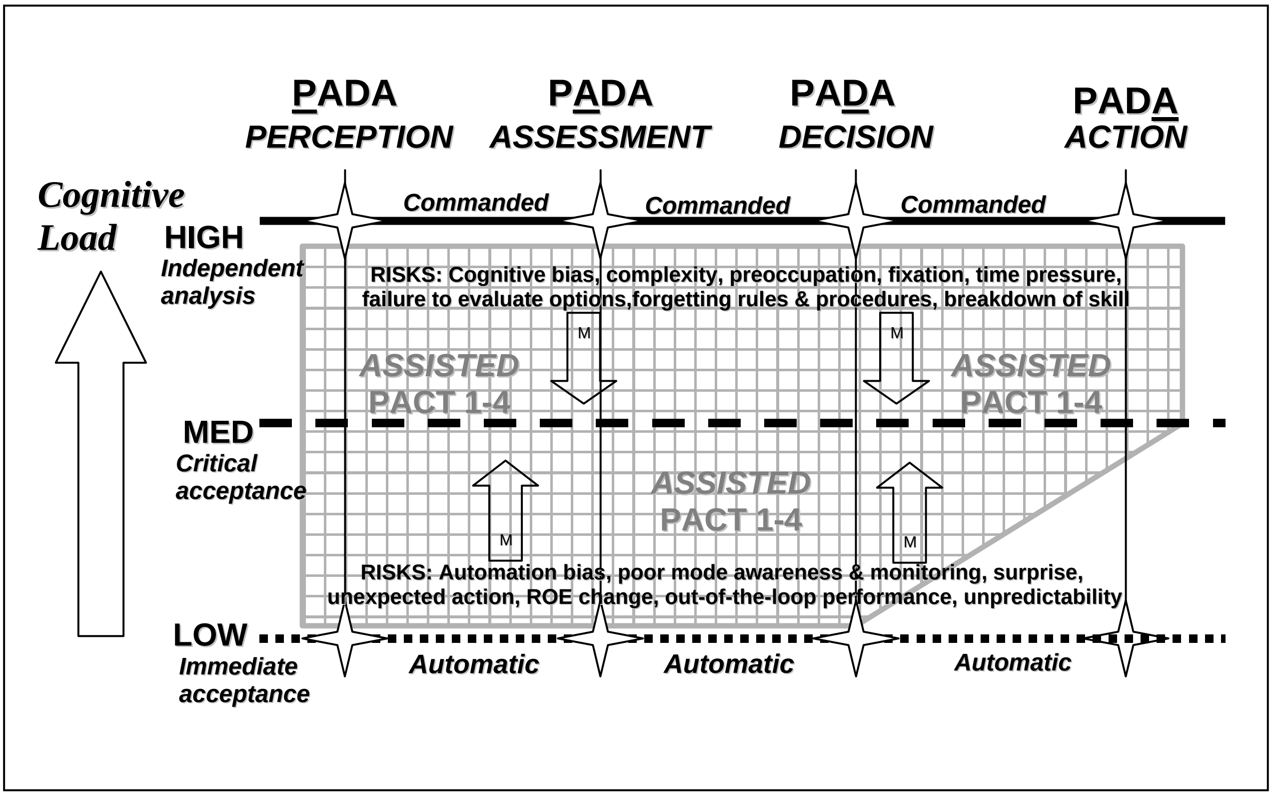


Figure 10. Cognitive load, risks and mitigation (M) for PACT levels

Phase of Work	COGMON	SASS	TIM	COGSIM
Requirements	KA Bespoke profile Empirical analysis Structuralist interference model of performance limitation	KA PC Pack Meta Pack Knowledge documents	KA GMTA COGNET	KA, GMTA, WDA Control task analysis PCT Cognitive Streaming SRK taxonomy DAT taxonomy EID Aiding HCI Style Guide
Specification and Design	Modular redundant architecture Near real-time Interleaved processing Polynomial decomposition Spectral analysis Regression analysis Coherence analysis Slow wave detection Loss line detection Artefact rejection and correction Rule-based artificial intelligence Recursive artificial neural networks	CommonKADS Organisational model Task model Agent model Knowledge model Communication model Design model	CommonKA DS based	Interface Design Document HTML Corba Sockets
Implementation	Ethernet protocol Risk PC C code ARM code Time critical assembly language Basic 5	CLIPS expert system shell. Ethernet protocol	Ethernet protocol Visual C++ Blackboard-based mission plan tracker	VAPS VEGA MultiGen FLSim STAGE LADBM Ethernet protocol
Simulation	Acorn RISC PC RISC-OS	Microsoft NT	Microsoft NT	Microsoft NT iGEN
Test and Evaluation	Iterative empirical validation F22 Computer game FMOE	FMOE Prototype story board Cognitive walk-through	FMOE Prototype story board Cognitive walk-through	Aiding Test plan PC-based and COGSIM-based experiments Iterative empirical validation FMOE

Table 2. Summary of COGPIT engineering methods, tools and techniques

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Medical Issues: The Future Impact of Biotechnology on Human Factors

Dr Steve Nicklin
DERA/DSTL Fort Halstead
Building S18, Room 72
Sevenoaks, Kent TN14 7BP
United Kingdom

Summary

Biotechnology within the military context can be defined as the "the exploitation and manipulation of biological systems to benefit overall military capability ". Recent years have witnessed a massive advance in scientific knowledge and capability mainly through the advent of molecular biology and genetic engineering techniques. These techniques have already led to considerable military benefits in the form of new countermeasures to chemical and biological warfare agents, novel sensors for the detection of explosives and equipment for bioremediation and environmental clean-up. In the future it is envisaged that advances in biotechnology will continue to provide advances particularly in the field of autonomous sensing systems and new and unique products and materials.

Introduction

The aim of this paper is to review the past, present and future of biotechnology in the context of health, human factors and subsequent defence applications.

The term biotechnology was coined in the early 1970s to describe industrial microbiological processes that either, harvest the products of naturally occurring free living cells / biological system or control and exploit their abilities within a manufacturing or process engineering context. However biotechnology is not new and is essentially a re-branding of a product from the 1930s when efforts were being made to use agricultural surpluses to produce plastic and hydrocarbon substrates. Examples include everything from modern brewing and cheese making, the production of antibiotics by fermentation, microbial conversion of simple chemicals (e.g. methanol and ammonia) into animal feed and production of fuel alcohol by fermentation.

In more recent years however biotechnology has been massively expanded through developments in genetic engineering and molecular biology that now allows the transfer of DNA from one organism to another. This approach provides the recipient organism with the "blue prints" necessary to produce an almost indefinite number of products. It is even possible to make completely artificial genes and generate molecules previously unknown in nature offering the almost limitless potential for the production of novel materials. Running in parallel with developments of genetic engineering techniques modern tissue culture and fermentation systems have also advanced significantly allowing cells and microbes to be grown under precisely controlled conditions allowing bulk production of a range of high value materials.

Utility of Biotechnology for Human Factors and Defence

Genetic manipulation and biotechnology clearly has many commercial and practical applications, a number of which readily lend themselves for exploitation and advancement by the military. These are summarised below and include the production of:

Antibiotics:

Micro-organisms make a number of anti-microbial products, with the antibiotics representing the major materials of military relevance. The major antibiotics of clinical significance include the beta-lactams e.g. penicillin and cephalosporin, and the aminoglycoside and tetra cyclin antibiotics. All these are typical

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secondary bacterial metabolites and whereas their industrial production is well understood the biochemistry and genetics of their biosynthesis is less clear. Genetic manipulation and mutation methods are now being used to manipulate the antibiotic producing organisms in order to obtain increased yields and a panel of faster acting, broad spectrum antibiotics capable of protecting against the more difficult target organisms and organisms that have evolved to be resistant to the normal clinically available antibiotics.

Vaccines:

A Vaccine is a biological material that induces immunity to an infectious agent. Many vaccines are in use today and provide protection against a wide range of childhood diseases and infectious agents and are particularly important for individuals travelling abroad. (see table 1). They are also used extensively within the veterinary and farming community to protect pets and livestock from endemic diseases. Historically, killed organisms were used as vaccines. Although very effective there is always the possibility that the killing process modified /reduced the effectiveness of the vaccine by reducing antigenicity of the organism or worse that the process failed to kill all of the organisms. Since in many instances the primary active ingredient of a killed vaccine is the outer protein coat it became increasingly attractive to attempt to produce vaccines containing only the outer immunogenic coat proteins. By genetic engineering, viral coat proteins can be cloned and expressed in living non-pathogenic carrier organisms thus allowing the development of safe, effective and convenient vaccines. Currently available genetically engineered vaccines include CMV, Hepatitis B, Measles, Rabies etc with the list including veterinary and experimental vaccines growing year on year. As one might expect a similar range of vaccines are also being developed to protect troops against Biological Warfare (BW) agents including amongst others plague, anthrax and botulism toxins. However vaccination doesn't stop with controlling disease. By using modified virus it is also possible to transfer other genetic capabilities and in the future it may also be possible to develop vaccines that endows the user with enhanced stamina and bigger and more effective muscle without the need for excessive training.

Bioactive Peptides and Designer Drugs:

Numerous biologically active proteins e.g. hormones, blood products, growth factors, antibodies, enzymes, and cytokines etc are of considerable medical importance. Historically these were collected and purified by direct isolation from tissues, blood or body fluids. The process is complicated and increasingly expensive. By cloning and over expressing the gene for a specific human protein in a host organism or cultured cell, large-scale production of biologically relevant proteins is possible (see table 1). The classic example of this process being the production of human insulin by transferring human DNA into E coli. This area of research has now been rapidly advanced by the pharmaceutical industry keen to develop and mass-produce new drugs and high value medicines by combining recombinant DNA technology and modern fermentation techniques. As alluded to above early work in this area focused on industrial exploitation of biotechnology for the production of high value and medically important natural gene products. Increasingly more recent research is directed towards the creation of new products (the so-called designer drugs) and the precise control of specific genes. However producing such genetic drugs is one thing, using them *in vivo* is another. Consequently much effort is also directed towards the packaging and delivery of these products and getting them into the correct cells and tissues.

Transgenic Organisms and Modified Foods

In addition to providing valuable drugs and medicines by microbial manipulation, genetic engineering now allows the advent of genetically modified whole plants and animals. By introducing cloned DNA into fertilized eggs of animals or directly into plant/animal cells grown in tissue culture, it is now possible to grow genetically modified (GM) higher organisms. Such organisms, referred to as transgenics, hold great promise for boosting agricultural production, improving the nutritional quality of meats and vegetables and producing a range novel proteins and products not normally produced in the host organisms. We already see crops being developed with genes conferring resistance to insects, pesticides, pollutants, herbicides and extremes of climate. Within a decade or so it is expected that we will see foods that are clinically/ pharmacologically active and able to provide increased vitamins, trace elements and even counteract various ailments such as non-insulin- dependant diabetes, cholera, high cholesterol and hepatitis B. Moreover, research within the US Combat Feeding program is already investigating the feasibility of producing small, high-density rations (the size of a pack of cards) that are intended to provide a soldier's nutritional and calorific needs for a full day. It is hoped that such foods

already termed "neutraceuticals" will not only provide calories but will be engineered to boost their immune systems. It has also been suggested that in certain environments or operations, soldiers could be equipped with emergency ration "biodigesters" containing immobilized enzymes or even living organisms that could convert locally acquired materials such as grass, leaves and insects into a nutritious (if unappetizing) meal.

Environmental Biotechnology: Impact & Military Duty of Care:

Because of evolutionary selection and environmental pressures from a wide and diverse range of natural habitats, bacteria provide a massive gene pool of capability, offering an enormous metabolic diversity. In order to survive in hostile environments, bacteria needed to evolve genes to allow them to coexist with the toxic elements within their immediate environment. As a consequence it is now possible to isolate genes for the biodegradation of many hazardous chemicals and wastewater pollutants. Genetic engineering and biotechnology is now beginning to exploit these resources for biotreatment of wastewater and contaminated land. Examples include genes for the biodegradation of chlorinated pesticides e.g. 2,4,5-trichlorophenoxyacetic acid (2,4.5-T), chlorobenzenes and related chlorophenolics, naphalines, toluenes, anilines and a growing list of solvents and hydrocarbons. In brief, the desired genes are isolated from species co-existing with the pollutant of interest and cloned into plasmids. These plasmids are then used to transfer genetic capability to other organisms. In this way it has been possible to transfer the ability to degrade explosives/hydrocarbons between organisms. Moreover it is perfectly possible to construct plasmids containing either single or multiple copies of genes for the degradation of a range of different toxic chemicals or pollutants. More recently this work has been extended to plants and trees allowing us to develop novel organisms capable of removing toxic pollutants from a range of contaminated environments including training areas and firing ranges (Fig 1). In addition to removing explosives contamination from the soil similar approaches have been developed to remove pollutants from submarine atmospheres, with future application being considered for space missions. Returning to more earthly issues biotechnology and biotreatment using mobile fermenters and processing plants are also being developed to treat waste water/sewage generated on ships and will eventually be required for similar applications in the battle field /war zone for processing local waste water and sewage etc.

Genetic Screening and Gene Therapy.

Researchers have long known that genetic alterations result in disease. Mutations in one gene may cause cystic fibrosis; in another it results in sickle cell anaemia, high blood pressure, depression, diabetes, dementia or even schizophrenia. But it is now becoming clear that genetic differences can also occur in how well a person absorbs, degrades and responds to various drugs. Moreover genetic variation can also render certain drugs toxic to certain individuals. Isoniazid, an anti- Tuberculosis drug adversely affects individuals who are slow acetylators. These individuals possess a less active form of the enzyme N-acetyltransferase, which normally clears the drug from the body. Similarly if slow acetylators are given procainamide, a drug commonly given after a heart attack, the recipients stand a good chance of developing a debilitating autoimmune disease. Thus in certain individuals a drug can actually out live its therapeutic utility and actually cause more harm than good. The gradual completion of the human genome programme is already opening up new areas of research. For example pharmacogenetics has recently emerged as a new area of science that aims to use a systematic analysis of genetic variation to understand idiosyncratic responses to drugs thereby enabling researchers to link particular genetic finger prints with differences in drug responsiveness. Genetic testing of this type could help match the right drug, treatment or vaccine at the right dose to the right soldier with out the risk of adverse effects. In the longer term genetic screening may even be able to predict how an individual might respond to changes in climate/environment, or how they might perform under stress. A linked area of research showing great promise is gene therapy i.e. the use of graftable genetic elements for the treatment of genetic diseases.

Biosensors

Biotechnology also underpins the rapidly growing field of biosensing. A biosensor is a device concerned with the detection of a specific target analyte (either biological/organic material or chemical vapour) through the use of appropriate biological receptors. In its simplest form, a biosensor device is comprised of three main elements; the biological receptor layer, a transducer to monitor binding effects between the receptor layer and its species/targets of interest, and a linking layer between these two. Bioreceptors come in a range of forms including antibodies, enzymes, olfactory binding proteins, DNA/RNA probes, synthetic ligands and cell surface

receptors, but to name a few (Fig 2). These biomolecules have evolved with the sole purpose of binding either firmly or reversibly to a range of target ligands in order to fulfil a specific biological or biochemical process.

Today many of these reagents find *in vitro* applications in a variety of sensor and detection systems. These biomolecules allow assays to be both exquisitely sensitive and highly specific and increasingly, further advances in modern biotechnology and molecular biology based techniques now provide a variety of "biological type reagents" never seen in nature. Problems still exist, however, and considerable effort is often required in order to get the biological molecules to behave as "nature intended" in an unnatural and hostile environment. For example, spacing, positioning and orientation of antibodies and enzymes are crucial to ensure maximum functionality and in many instances the chemists involved in coupling ligands to surfaces are more important to the success of a sensor system that the biologist who provides the reagents.

The transducer is usually chosen for its sensitivity to changes produced when the biological receptor binds to, or reacts with, the target material. The system is arranged to minimise or prevent false alarms. In their simplest format biosensors may take the form of a clinical dipstick or ELISA based diagnostic kit generating a coloured signal, the intensity of which is proportional to the analyte concentration. Others are more complex and are designed to monitor changes in optical, electrical or mass changes and include surface plasmon resonance (SPR) and evanescent wave (optical transducers), electrochemical or impedance cell arrangements and ISFETS (electrical transducers), or quartz crystal microbalance and surface acoustic wave devices (mass transducers).

Biosensor research began in the 1960's with the development of glucose sensors, many of which are now marketed as over the counter products. In a military context however, it is also particularly noteworthy that the current in-service nerve agent detector (NAIAD) is a biosenor utilising an immobilised enzyme (acetylcholine esterase) as the key recognition element within the sensor. Similar sensors are also under development for the detection of pesticides, pollutants and explosives etc. Much of the current research in this field explores the utility of other bioreceptors and in particular antibodies, as the key recognition element within various types of sensor arrays. The research effort is currently being directed at linking receptor molecules, (which, provide the specificity to the system), on to supporting surfaces e.g. silicon, metal, polymers, colloids etc in such a way that the binding of a target analyte is detected in real time. Whereas these methods demonstrate the proof of principal and the validity of the approach, it is likely that future years will witness further advances, in particular, in the miniaturisation of the arrays through silicon based micro-nanofabrication techniques. In the longer term other biological molecules such as enzymes and olfactory protein might replace antibodies to provide even higher levels of specificity and sensitivity.

Autonomous Sensors

Ultimately the merger of biosensors with micro/nanoelectronics will provide the future generation of smart sensors. Moreover it is also likely that by combining these approaches with biocompatible materials and suitable telemetry it will eventually prove possible to attach or implant sensors into individuals. These sensors could be designed to be capable of not only providing physiological outputs (e.g. cardiovascular / respiratory parameters and body temperature) but also sense and report on other parameters e.g. stress and may even be able to warn against the threat of infection. Similarly by incorporating therapeutic elements within such devices they may also be able to release agents to directly into the tissues /blood to improve wound healing and/or counter stress, infection, nerve agents etc. There are also designs to investigate the utility of devices referred to as transdermal nutrient delivery systems (TNDSs), these systems are intended to deliver nutrients/water into soldiers during times of intense conflict/confinement when they are unable to take in food or water normally.

Tissue replacement and Biomimetics

As early as 1965 researchers at the University of California LA demonstrated that new bone growth could be "seeded" in animals that received a powdered bone implant. This observation lead to the isolation and cloning of a family of proteins known as bone morphogenic proteins (BMPs) . Various clinical trials are now underway to test the ability of these agents to promote bone growth in accident victims. Encouraging growth *in vivo* is one thing but growing replacement tissues or even organs *in vitro* is a significantly more complex task since tissues that are more than a few mm thick need capillaries to grow into them in order to supply nutrients. This is also being addressed through modern tissue culture techniques which in combination with genetically engineered growth factors now allows us to culture and grow human skin (suitable for skin grafting) within the

laboratory. In future we also anticipate the production of replacement bone and collagen for use in reconstructive surgery. However despite these major advances in tissue engineering the construction or replacement of fully functional organs remains many years away. Others believe that by developing and engineering materials based on nature /natural products through biomimetics it will also be possible to develop a whole range of novel and improved man-made materials, including biopolymers and fabrics. For example one could envisage a second skin like material being worn next to the skin containing artificial capillary nets capable of absorbing and neutralising toxins, with enzymes to degrade nerve agents, and even clotting agents to facilitate wound healing. In an ideal world the fabric, would change colour to blend with the environment, generate electricity through body movement and be edible!

Issues and Concerns

Despite the undoubted promises offered by biotechnology and genetic engineering, developing useful products is still an enormous and often expensive undertaking. Other than the technological problems of correctly cloning and expressing the gene of interest, the cost of purifying the products and subsequent matters such as clinical trials and government approval must also be considered. As with any new product intended for human "consumption" all new GE products intended for human or veterinary use must pass extensive clinical trials. For example human insulin produced by recombinant DNA technology had to pass strict trials in human volunteers despite the fact that the microbially produced insulin was shown to be identical to protein made by humans. In addition public perception and concerns over Genetically Modified Organisms entering the food chain need to be respected and treated with due care and diligence. Conversely, we should not underestimate the power and potential threat posed by biotechnology and the harm that it can do if purposely abused. Many countries including potential aggressors already posses all the skills and knowledge they require to develop "biotech" weapons. Whether these be overt attacks with biological agents and toxins or more subtle attacks via ecological, environmental or economic means, the "gen(i)e" now is out of the bottle and can never be put back!

Table 1 Medicinal Products Produced by Recombinant DNA Techniques	
Gene Product	**Activity**
Vaccines	
Rabies	Short Term Protection from Disease
Measles	Long term Protection from Disease
Cytomegalovirus	Prevention of Infection
Hepatitis B	Protection from serum Hepatitis
PA Proteins	Protects against Anthrax
F1/V	Protects against Plague
Etc....	
Blood Products	
Factors VII, VIII, IX	Facilitates Blood Clotting
Erythropoietin	Stimulates Erythrocyte Production
Tissue Plasminogen Activator	Clot Buster
Urokinase	Facilitates Blood Clotting
Bone Morphogenic Protein	Stimulates Bone Growth
Enzymes	Range of Bio-Catalytic Agents
Etc....	
Immunomodulatory Agents	
Alpha-Interferon	Immunmodulator
Beta-Interferon	Immunmodulator
Colony Stimulating Factor	Stimulatory Agent
Lysozyme	Reduces Inflammation
Tumour Necrosis Factor	Attacks Tumours
Interleukins	Immunostimulatory agents
Cytokines	Cell Activation Proteins
Etc...	
Hormones	
Insulin	Treats Diabetes
Epidermal Growth Hormone	Speeds Wound Healing
Nerve Growth Factor	Promotes Nerve Growth
Etc.....	
NB ! New Human and Veterinary Products are Emerging Continually	

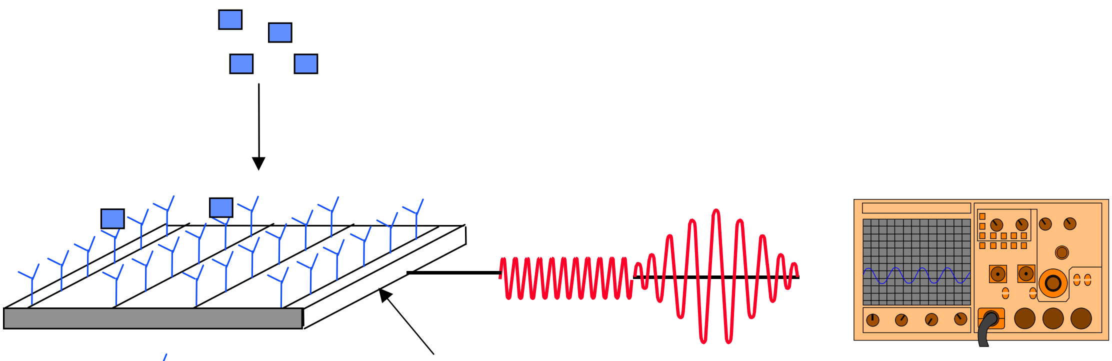
Fig1

Worlds First Genetically Engineered " Explosive Degrading" Plant

Fig 2

Schematic representation of a biosensor with some of the different options for the transducer and biological receptors.

Analyte (target or its emission)



Receptors ( )
Antibody
Enzyme
Olfactory receptors
DNA/RNA probes
Synthetic Peptides

Transducer
Electrical (ISFETS, Porous silicon)
Optical (SPR/evanescent wave)
Acoustic (SAW, QCM)

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Engineering Interactive Systems Through Formal Methods for Both Tasks and System Models

D. Navarre, P. Palanque, R. Bastide
LIHS, University Toulouse 1
Place Anatole France, 31042 Toulouse Cedex
France
{navarre, palanque, bastide}@univ-tlse1.fr

1 SUMMARY

This paper presents a set of tools supporting the development of interactive systems using two different notations. One of these notations, called ConcurTaskTrees (CTT), is used for task modelling. The other notation, called Interactive Cooperative Objects (ICO), is used for system modelling. Even though these two kinds of models represent two different views of the same world (users interacting with interactive systems), they are built by different people and used independently. The aim of this paper is to propose the use of scenarios as a bridge between these two views. On the task modelling side, scenarios are seen as possible traces of activities, while on the system side, they are viewed as traces of actions. This generic approach is presented in a case study in the domain of Air Traffic Control.

2 INTRODUCTION

The research area of model-based design and evaluation of interactive applications (Paternò 99) aims at identifying models able to support design, development, and evaluation of interactive applications. Such models highlight important aspects that should be taken into account by designers. Various types of models, such as user, context, and task models, have proved to be useful in the design and development of interactive applications.

In particular, interactive systems are highly concurrent systems, which support several devices media and tools, and are characterised by dialogues and the presentations they provide for communicating information to users. However, to build effective presentations it is important to understand the activities that users want to perform with them. Such activities can be highly concurrent with even multi-user interactions and such concurrency is a source of flexibility but at the same time has to be carefully designed and controlled.

In addition, we have to take into account that the concurrency provided to users needs to be supported by the system underneath. Thus we need not only models for specifying user activities while interacting with the system, but also for specifying the underlying system. Such models should allow different levels of refinement depending on the needs of the users and should be powerful enough to express all the different relationships occurring among the various components without introducing too many low-level details.

Having models is not sufficient to support a formal analysis, methods and tools are strongly requested to help designers use the information contained in such models during their work. In particular, in the field of model-based approaches to human-computer interaction only recently tools supporting such approaches have started to be developed. Unfortunately, often such tools are rather rudimentary, usable only by the groups that developed them. Even less attention has been paid to the integration of models and tools developed for different purposes. In this paper we present the results of a work that aims to overcome this limitation. In particular, we show and discuss how we have reached the integration of a set of tools for task modelling with a set of tools for user interface system modelling through the use of abstract scenarios. The goal of such integration is to provide designers with an environment enabling them to see, for example, how a sequence of user tasks can be related to the specification of the behaviour of the underlying system's interconnecting components.

In the paper, after a short discussion of related works, we recall the basic concepts of the approaches and tools that we aim to integrate. Then, we discuss the architecture of the solution identified. As both the CTT and ICO notations are tool supported (the environments are respectively CTTE and PetShop), an integration tool (implemented at LIHS) based on this notion of scenarios is presented. An application example of the integrated set of tools is discussed before drawing some concluding remarks. The case study presented has been addressed in the European Project MEFISTO, which is a long-term research project dedicated to the design of safety critical interactive systems with the support of formal methods. In particular, the project has focused on the air traffic control domain from which this case study has been drawn.

3 RELATED WORK

The use of models has often been criticised for the effort required to develop them and the difficulties in using the information that they contain to support design and evaluation. After having carefully evaluated the need for introducing a new notation, the first concern should be providing users with tools to make its use easier and more effective. The problem is that getting used to another notation involves a significant amount of effort and time spent by the potential users in order to understand features, semantics and meaning of the notation's conventions. In addition, even when users

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have understood the main features of the notation, there is still the risk that their effort might be wasted if they find that using it is difficult and not really feasible or appropriate for intensive use and real case studies.

Indeed, one of the strengths of a notation is the possibility of supporting it through automatic tools. Developing a formal model can be a long process, which requires a considerable effort. Automatic tools can ease such activity and can help designers to get information from the models, which is useful for supporting the design cycle.

Some research prototype was developed years ago to show the feasibility of the development of such tools, however the first prototypes were rather limited in terms of functionality and usable mainly by the people who develop them. Only in recent years some more engineered tools have been developed, in some cases they are also publicly available. For example, Euterpe (van Welie et al. 98) is a tool supporting GTA (Groupware Task Analysis) where task models are developed in the horizontal dimension with different panels to edit task, objects, actors. A simulator of task models of single user applications has been given with the support of an object-oriented modelling language (Biere et al. 99).

Mobi-D (Puerta & Eisenstein 99) and Trident (Bodart et al. 94) are examples of tools aiming to use information contained in models to support design and development of user interfaces. In particular, in Mobi-D the designer can choose different strategies in using the information contained in task and domain model to derive the user interface design.

In our work we envision a solution based on the use of two tools (CTTE and PetShop) developed to support two different types of models. The former is a tool for task modelling supporting a unique set of functionality (simulation of models of cooperative applications, comparison of task models, support of use of scenarios to develop task models, …). The latter supports system models described using Petri nets in an object-oriented environment. PetShop is able to support editing of a Petri Net controlling the dialogues of a user interface even at run-time thus allowing dynamic change of its behaviour. Their integration allows thorough support to designers since early conceptual design until evaluation of a full prototype.

4 OUR APPROACH

Various models have been proposed in the human-computer interaction field. Task and system models are particularly important when designing and developing interactive software systems. In both industrial and academic communities there is a wide agreement on the relevance of task models as they allow expressing the intentions of the users and the activities they should perform to reach their goals. These models also allow designers to develop an integrated description of both functional and interactive aspects. Within the development lifecycle of an application the task-modelling phase is supposed to be performed after having gathered information on the application domain and an informal task analysis phase. The result of the latter one is an informal list of tasks that have been identified as relevant for the application domain.

After this step, in developing a task model designers should be able to clarify many aspects related to tasks and their relationships. In some cases task models are first developed and then used to drive the system design. In other cases designers have to address an existing system and need to develop a task model to better understand and evaluate its behaviour (Palanque & Bastide 97).

System models describe important aspects of the user interface. In this work we pay particular attention to the dialogue supported by the system: how user actions and system feedback can be sequenced. Scenarios (Carroll 95) are a well-known technique in the human-computer interaction area. They provide a description of one specific use of a given system, in a given context. They are an example of usage. Their limited scope is their strength because they can easily highlight some specific aspect and are easily understood and remembered. Thus, they can also be considered as a useful tool to compare different models and analyse their relationships.

One point is that we can check if the task models fulfil the expected requirements and if the system model matches the planned behaviour. However, what cannot be missed is checking if both two models are consistent, which means if both specifications really refer to the same system. This requires checking if for each user action assumed in the system model there is an actual counterpart in the task model, and each system output provided to the user has been foreseen in the task model specification.

Another relevant point that has to be highlighted is that these two models can be specified by different people and in distinct moments of the design cycle of the user interface development process. Indeed, especially in real case studies sometimes the task models will be developed at first, sometimes they might be specified after the system model has already been obtained. So, we need an approach that does not have specific constraints and requirements on what is assumed to be available at a certain phase of the system design, as it can be equally used efficiently in both cases.

In our approach, we used abstract scenarios as the common "lingua franca" to ensure that there is actual correspondence between what has been specified within the task model and what has been specified in the system model. The idea is to focus the attention on specific examples of usage either on the system side or on the tasks side and to check if on these simple examples of the system use such correspondence exists.

Considering the task model-side, in our approach we used the ConcurTaskTrees notation for specifying tasks. The formal semantics of the operators used in this notation is in (Paternò 00). This notation allows users to explicitly express how the allocation of the different tasks has been assumed in the system design. Such allocation could be on the user alone (user tasks), on the application alone (application tasks), on the interaction between the user and the application (interaction tasks), or if the activity is too general to be specifically allocated on each of them (abstract task). Explicit indication of task allocation is one aspect which makes the notation very suitable for designers of interactive systems, because they have to explicitly indicate which part of the interactive system (user, application, interaction between them) has to undertake each task.

This aspect proves to be effective especially when both comparison and integration of different models has to be carried out, such as in our case. The notation provides the ability to specify in the task model when system support is requested on the user interface. This allows comparing and cross-checking if the task model reflects and is adequately supported by the corresponding system model. More specifically, the points that have to be carefully checked in the task model specification are the interaction and application tasks. Application tasks indicate that at a certain point during a session a specific behaviour of the system is expected. This behaviour can be expressed in terms of a specific feedback of an action the user has performed while interacting with the system; in terms of a result the system has produced after some elaboration; in terms of availability of a specific input needed to users in order to perform their tasks. All those possibilities have to be carefully supported especially if the considered domain is vast and complex as the air traffic control field considered in our case study. Such domain is composed of a number of entities that maintain a complex relationship structure, due to their internal structure and to the dynamic behaviour they follow, which has to be appropriately presented to the users.

5 A CASE STUDY

This case study has been considered in the European Project MEFISTO which is a long term research project dedicated to the design of safety critical interactive systems, with particular attention to the air traffic control application domain.

After a short overview of the case study in sub-section 4.1, this section presents the various models built in order to represent both predictive user activities and the system under consideration. Subsection 5.2 presents the use of CTT and its environment for tasks modelling and simulation as well as the identification of scenarios from the task models. Sub-section 5.3 presents the use of the ICO formalism and its support environment Petshop for modelling and executing interactive systems.

5.1 Informal description of the case study

This example is taken from a case study related to En-route Air Traffic Control with the support of data-link technologies in the ATC field. Using such applications air traffic controllers can communicate with pilots in a sector (a portion of the airspace) through digital commands. In particular, we focus on the activities related to when an aircraft changes air sector.

A representation of the radar image is shown in Figure 1. On the radar image each plane is represented by a graphical element providing air traffic controllers with useful information for handling air traffic in a sector. In the simplified version of the radar image we are considering, each graphical representation of a plane is made up of three components: a label (providing precise information about the plane such as ID, speed, cleared flight level, …), a dot (representing the current position of the plane in the sector) and a speed vector (a graphical line from the dot which represent the envisioned position of the plane in 3 minutes).

An Air Traffic Control simulator is in charge of reproducing the arrival of new planes in the sector while in reality they would be instantiated on the user interface by calls from the functional core of the application processing information provided by physical radars.

Initially the radar image is empty. Each time a new plane is randomly generated it is graphically represented on the radar image. It is possible for the user to select planes by *clicking* on its graphical representation. *Clicking* on the flight representation will change its state to the *Assume* state meaning that the air traffic controller is now in charge of the plane. Assuming the plane changes its graphical representation as it can be seen on the right-hand side of Figure 1. Once a plane is assumed, the controller can send clearances to this plane. In this case study we only consider the change of frequency functionality corresponding to the controller's activity of transferring a plane to an adjacent sector. When the plane has been taken on, the button 

is enabled (see plane 1123 on the right-hand side of Figure 1). Clicking on this button opens a menu allowing the controller selecting the new value for the frequency.

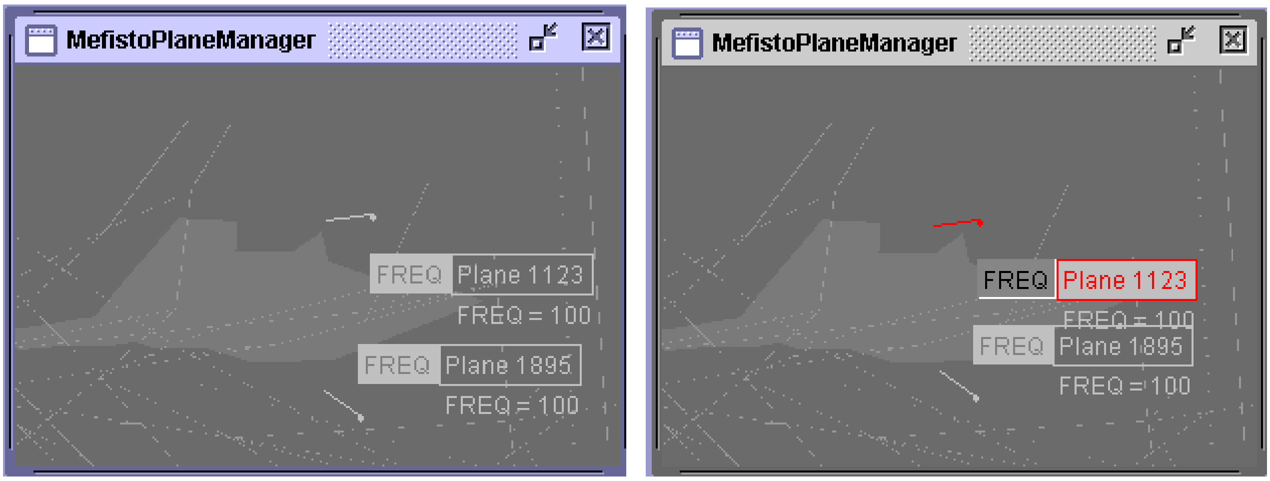

Figure 1. A screen shot of the radar screen with planes (right-hand side, one the planes 1123 is assumed)

5.2 The ConcurTaskTrees Notation and Environment used in the Case Study

We first introduce the notation for task modelling that has been used and the related environment.

5.2.1 The ConcurTasktrees Notation

There are various approaches that aim to specify tasks. They differ in aspects such as the type of formalism they use, the type of knowledge they capture, and how they support the design and development of interactive systems. In this paper we consider task models that have been represented using the ConcurTaskTrees notation (Paternò 99). In ConcurTaskTrees activities are described at different abstraction levels in a hierarchical manner, represented graphically in a tree-like format (see figure 2 for an example). In contrast to previous approaches, such as Hierarchical Task Analysis, ConcurTaskTrees provides a rich set of operators, with precise meaning, able to describe many possible temporal relationships (concurrency, interruption, disabling, iteration, and so on). The notation allows designers to obtain concise representations describing many possible evolutions over a user session. The formal semantics of the operators has been given in (Paternò 00). The notation also supports the possibility of using icons or geometrical shapes to indicate how the performance of the tasks is allocated.

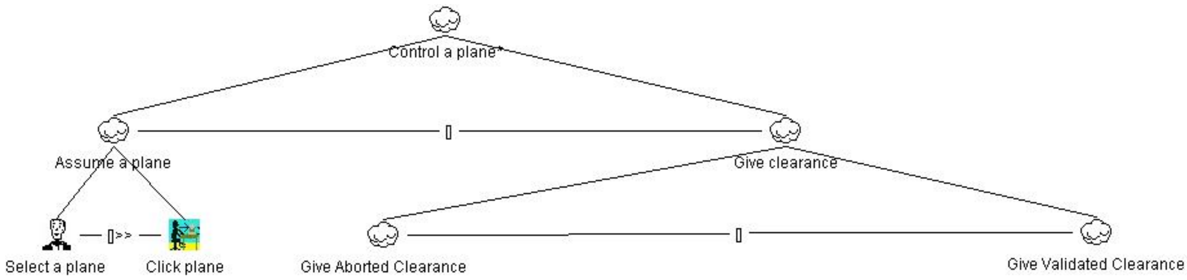

Figure 2. The abstract task model of the case study

For each task it is possible to provide additional information including the objects manipulated (for both the user interface and the application) and attributes such as frequency. In addition, as in the design of complex cooperative environments more and more attention is being paid to the horizontal mechanism of coordination between different roles, ConcurTaskTrees allows designers to specify explicitly how the cooperation among different users is performed.

We give an overview of the main features of the notation by commenting on two excerpts of specification from the considered case study.

The activity of controlling a plane (*Control a plane*) is an iterative task (* is the iterative operator) which consists of either assuming a plane (*Assume a plane* task) or giving clearance to the plane (*Give clearance* task). Those two activities are mutually exclusive, as you can see from the choice operator []. The activity of assuming a plane is composed of deciding which plane has to be assumed (*Select a plane* task, the associated icon emphasizes the cognitive nature of this *user* task). Once this activity has been performed it is possible to select the button related to the plan (see the Enabling operator with information passing []>>, which highlights that only after the first activity has been carried out and delivered information to the second task, the latter can be performed). In addition, the *Click plane* task requires an explicit action of the controller on an element of the user interface so it belongs to the category of *interaction* tasks and the appropriate icon has been used. The *Give clearance* task is composed of two different activities: *Give Aborted*

Clearance and *Give Validated Clearance*, depending on whether the clearance has been aborted or not. Each of these two activities is a high-level one, whose performance cannot be entirely allocated either to the application alone, or to the user alone, or to an interaction between the user and the system: this is expressed by using a cloud-shape icon associated to the so-called *abstract* tasks. The specification of each of these two tasks is described in Figure 3.

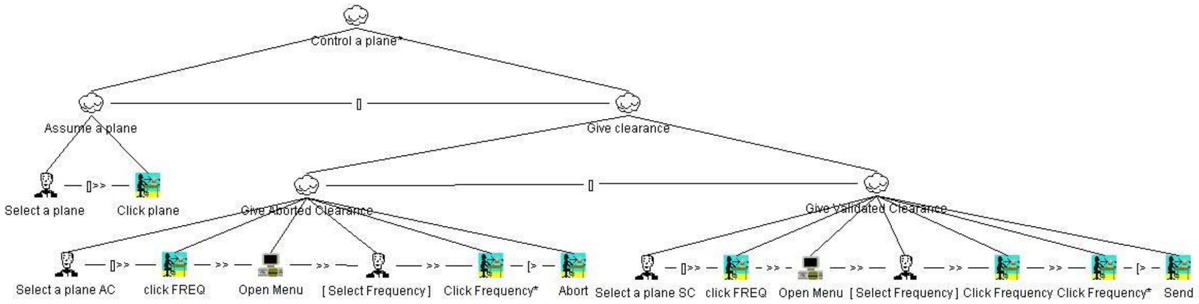

Figure 3. The concrete and detailed task model of the case study

The *Give Aborted Clearance* task is composed of the controller's cognitive activity of selecting a plane (*Select a plane AC*), then they select the button related to the frequency (*Click FREQ*). This triggers the opening of the associated menu on the controller's user interface (*Open Menu*, note the icon associated to the category of the *application* tasks), then the controller can think about a specific frequency (in the task model the possibility of performing or not this task is expressed by the option operator represented by squared brackets [T], see the *Select Frequency* task). Then, controllers choose the appropriate value of frequency within the user interface (*Click Frequency* task, which can be performed more than one time, as you can see from the iterative operator *) until they decide to interrupt the entire activity (see the Disabling operator "[>" which refers to the possibility for the second task to disable the first one), by selecting the related object in the user interface (*Abort* task).

In case of a clearance that is sent to the pilot (*Give Validated Clearance*), the sequence of actions is mainly the same, apart from the last one (*Send* task), with which the controller sends the clearance to the pilot.

A set of tools have been developed to specify task models for co-operative applications in ConcurTaskTrees and to analyse their content. The CTTE tool (Paternò et al., 01) has various features supporting editing of task models. It can automatically check the syntax of the specification, give statistical information, compare task models, simulate their behaviour and give examples of scenarios of use. The CTTE editing environment is intended as a computer-based support tool for CTT, and is freely downloadable from http://giove.cnuce.cnr.it/ctte.html.

The tool has been used in a number of projects and at several universities for teaching purposes. It was used to support design of an adaptable web museum application. The application provided different ways to navigate and present information depending on the current user model (tourist, expert, student). We developed a task model for each type of user. The task models also shared some portions for tasks that were common to different types of users. In the MEFISTO project, CTTE has been used to model various air traffic control applications and support their design and evaluation. Large specifications, including hundreds of tasks, were developed. In this project the tool was proposed to several teams belonging to organizations that design and develop systems for air traffic control; in some cases the teams also included people with different backgrounds. At the University of York an evaluation exercise was developed using a number of techniques (including cognitive dimensions for notations and cooperative evaluation). In the GUITARE project, various teams from software companies have used the tool for different application domains. Some of these teams included people without any background in computer science, who nevertheless were able to use the tool satisfactorily. Methods have also been developed for supporting user interface design and generation starting with task models specified by CTTE.

With this tool becomes very intuitive and effective to exploit the graphical and hierarchical nature (tree-like format) features of the notation by all the operations (cut, paste, insert) that are possible on tree-like structures. In addition, even the specific layout selected for the tool conveys further useful information about the notation. For instance, the relative positions of the user interface objects presenting the operators within the tool convey information about their priorities (sorted top to bottom from highest to lowest operator priority). In addition, it is possible to recall the meaning of any operator by means of useful tool tips available within the environment (such feature is found very useful especially by users who are rather new to the notation and unable to recall the meaning of the operators). Finally, the ability to structure the specification with some tasks that can be referenced both in the single-user and cooperative parts is well supported by the environment because it allows easy switching between these different views. These simple examples, relative to the case of the CTT notation, serve to highlight the extent to which the use of a suitable tool can support users while building the task specifications.

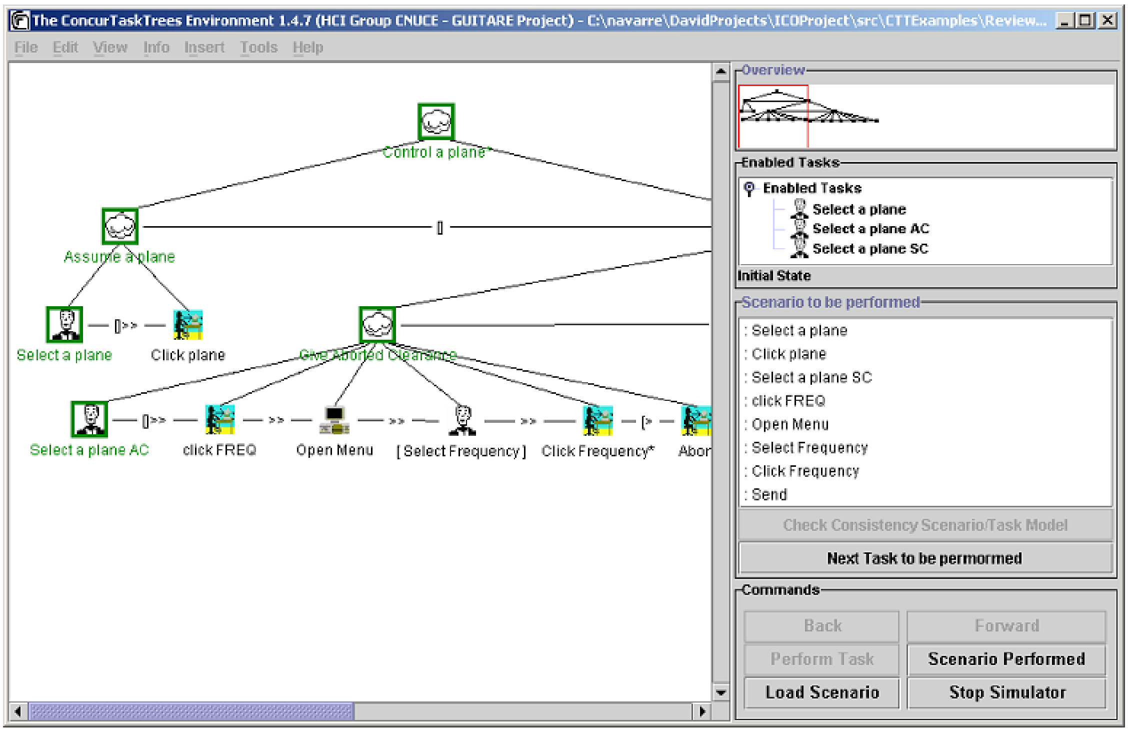

Figure 4. CTTE for extracting scenarios

In Figure 4 the simulator provided in the CTT Environment is shown. The simulator has been implemented following the formal semantics of the CTT notation. When this tool is activated, in the left-hand part of the window it is possible to highlight (by means of a different colour) all the tasks that are enabled at any moment of the simulation. This means all the tasks that can be performed at a specific time, depending on the tasks that have been previously carried out. The execution of a task can be performed either within the graphical panel on the left (a task can be executed by double-clicking on the related task icon), or by selecting the task name within the list of "Enabled tasks" panel on the right. In addition, it is possible to load a previously created scenario. Its composing tasks will appear in the "Scenario to be performed" list from where it is possible to simulate its performance again.

As an example of scenario we have chosen to extract from the task model of Figure the following trace of low-level tasks (this scenario has been generated using CTTE and is displayed on the right-hand side of Figure 4):

- First the controller selects one of the planes not assumed yet (this is a user task)
- Then the controller clicks on this plane to assume it (interaction task)
- Then the controller decides to change the current frequency of one of the flight assumed (user task)
- then the controller clicks on the label FREQ to open the data-link menu (interaction task)
- then the controller selects (in his /her head) a new frequency for this plane (user task)
- then the controller clicks on one of the available frequencies for this plane (interaction task)
- then the controller clicks on the SEND button to send the new frequency to the aircraft (interaction task)

The performance of this scenario on the system model will be detailed in section 6.2.

5.3 ICOs and PetShop used in the Case Study

System modelling is done using the ICO formalism and its development environment is called PetShop. Both of them are presented through the case study. The ICO formalism is the continuation of early work on dialogue modelling using high-level Petri nets (Bastide & Palanque 90).

5.3.1 ICO formalism

The various components of the formalism are introduced informally hereafter and all of them are fully exemplified on the case study. A complete and formal presentation of this formalism can be found in http://lihs.univ-tlse1.fr/palanque/Ps/ICOFormalDef.pdf.

The Interactive Cooperative Objects (ICOs) formalism is a formal notation dedicated to the specification of interactive systems. ICOs use concepts borrowed from the object-oriented approach (dynamic instantiation, classification, encapsulation, inheritance, client/server relationship) to describe the structural or static aspects of systems, and uses high-level Petri nets to describe their dynamic or behavioural aspects. ICOs were originally devised for the modelling and implementation of event-driven interfaces. An ICO model of a system is made up of several communicating objects, Petri nets describe both behaviour of objects and communication protocol between objects. In the ICO formalism, an object is an entity featuring four components: services, behaviour, state and presentation.

Services (or Interface): The interface specifies at a syntactic level the services that a client object can request from a server object that implements this interface. The interface details the services supported and their signature: a list of parameters with their type and parameter-passing mode, the type of the return value, the exceptions that may possibly be raised during the processing of the service. For describing this interface we use the CORBA-IDL language (OMG 98). An ICO offers a set of services that define the interface (in the programming language meaning) offered by the object to its environment. In the case of user-driven application, this environment may be either the user or other objects of the application. The ICO formalism distinguishes between two kinds of services: services offered to the user (user services) and services offered to other objects.

Behaviour: The behaviour of an ICO defines how the object reacts to external stimuli according to its inner state. This behaviour is described by a high-level Petri net called the Object Control Structure (ObCS) of the object.

State: The state of an ICO is the distribution and the value of the tokens (called the marking) in the places of the ObCS. This defines how the current state influences the availability of services, and conversely how the performance of a service influences the state of the object.

Presentation: The Presentation of an object states its external appearance. It is made up of three components: the widgets, the activation function and the rendering function. This Presentation is a structured set of widgets organized in a set of windows. The user - system interaction will only take place through those widgets. Each user action on a widget may trigger one of the ICO's user services. The relation between user services and widgets is fully stated by the activation function that associates the service to be triggered to each couple (widget, user action). The rendering function is in charge of presenting information according to the state changes that occur. It is thus related to the representation of states in the behavioural description i.e. places in the high-level Petri net.

ICOs are used to provide a formal description of the dynamic behaviour of an interactive application. An ICO specification fully describes the potential interactions that users may have with the application. The specification encompasses both the "input" aspects of the interaction (i.e. how user actions impact on the inner state of the application, and which actions are enabled at any given time) and its "output" aspects (i.e. when and how the application displays information that is relevant to the user). An ICO specification is fully executable, which gives the possibility of prototyping and testing quickly an application before it is fully implemented. The specification can also be validated using analysis and proof tools developed within the Petri nets community.

5.3.2 ICO environment (PetShop)

In this section we introduce the PetShop environment and the design process it supports. The interested reader can find more information in (Sy et al. 99).

Figure 5 presents the general architecture of PetShop. The rectangles represent the functional modules of PetShop. The documents-like shapes represent the models produced and used by the modules.

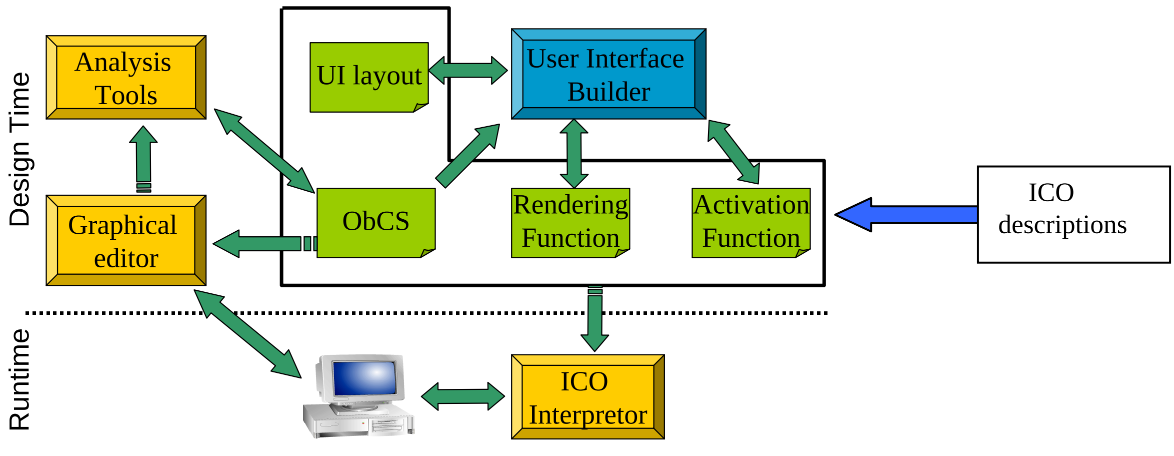

Figure 5. Tools available for designers in PetShop Environment

5.3.3 Presentation of ICOs and PetShop on the case study

In this section we only present a subset of the set of classes and objects of the case study specification. However, a complete description of the specification can be found in (Navarre et al. 00).

In this paper the case study is modelled as a set of three cooperating classes: MefistoPlaneManager, MefistoPlane and MefistoMenu. These three classes are full fledged and we will describe successively their components.

5.3.3.1 *The class MefistoPlaneManager*

The class MefistoPlaneManager is the class in charge of handling the set of planes in a sector. Each time a new plane arrives in the sector the MefistoPlaneManager instanciates it from the class MefistoPlanes (see section 5.3.3.2). During the execution this class will only have one instance. The set of services offered by this class is described in Figure 6.

```
interface MefistoPlaneManager {
   void closePlane(in MefistoPlane p);
   void terminatePlane(in MefistoPlane p);
   void addPlane(in MefistoPlane p);
};
```

Figure 6. IDL description of the class MefistoPlaneManager

This IDL description shows that the class offers three services dealing with the managing of the planes in a sector: adding a plane, terminating a plane (when it leaves a sector) and closing the menu of a plane.

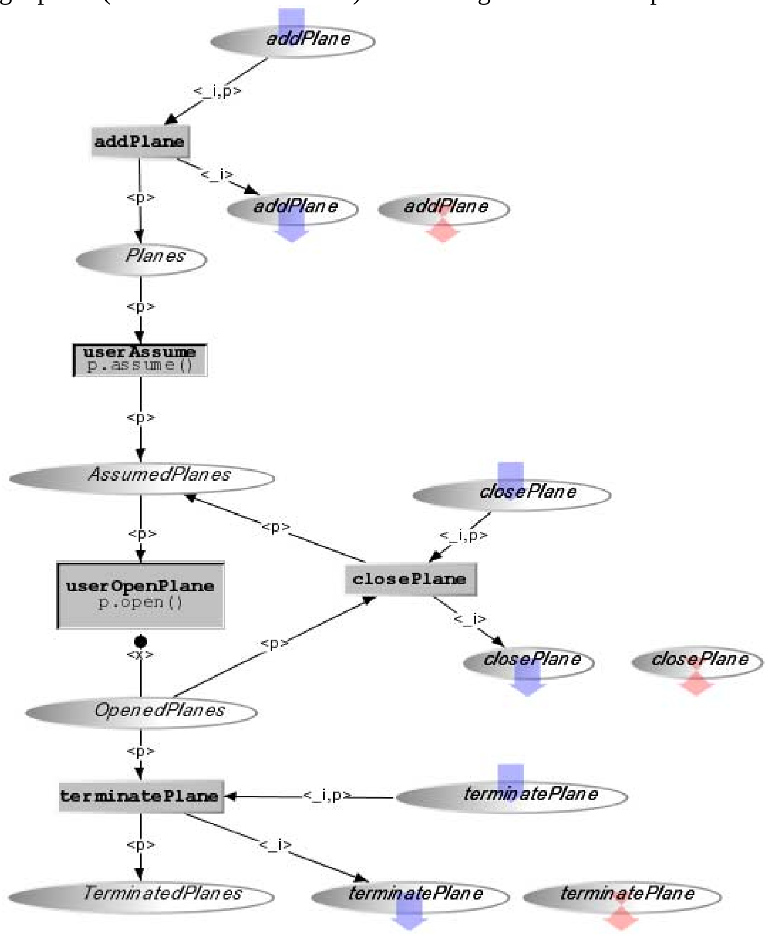

Figure 7. ObCS description of the class MefistoPlaneManager

Figure 7 presents the behaviour of this i.e. the state of the class and, according to the current state, what the services available to the other objects of the application are. The transition UserOpenPlane has an input arc from place *AssumedPlanes* meaning that a controller can only open a menu on a plane that has previously been assumed. The inhibitor arc between that transition and the place OpenedPlanes states that only one plane at a time can have the data-link menu opened.

Widget		**Event**	**Service**
Place	**Type**		
Planes	Plane	LabeClick	userAssume
AssumedPlanes	Plane	ButtonClick	userOpenMenu

Figure 8. The activation function of the class MefistoPlaneManager

ObCS Element	Feature	Rendering method
Place Planes	token <p> enterred	p.show()

Figure 9. Rendering function of the MefistoPlaneManager

Figure 8 and Figure 9 describe the presentation part of the ICO MefistoPlaneManager. From the rendering function it can be seen that this class only triggers rendering through the class MefistoPlane as each time a new token enters in the place Planes the graphical function Show is triggered on the corresponding plane.

5.3.3.2 The class MefistoPlane

```
interface MefistoPlane {
   void open();
   void close();
   void assume();
   void validate(in short x);
};
```

Figure 10. IDL description of the class MefistoPlane

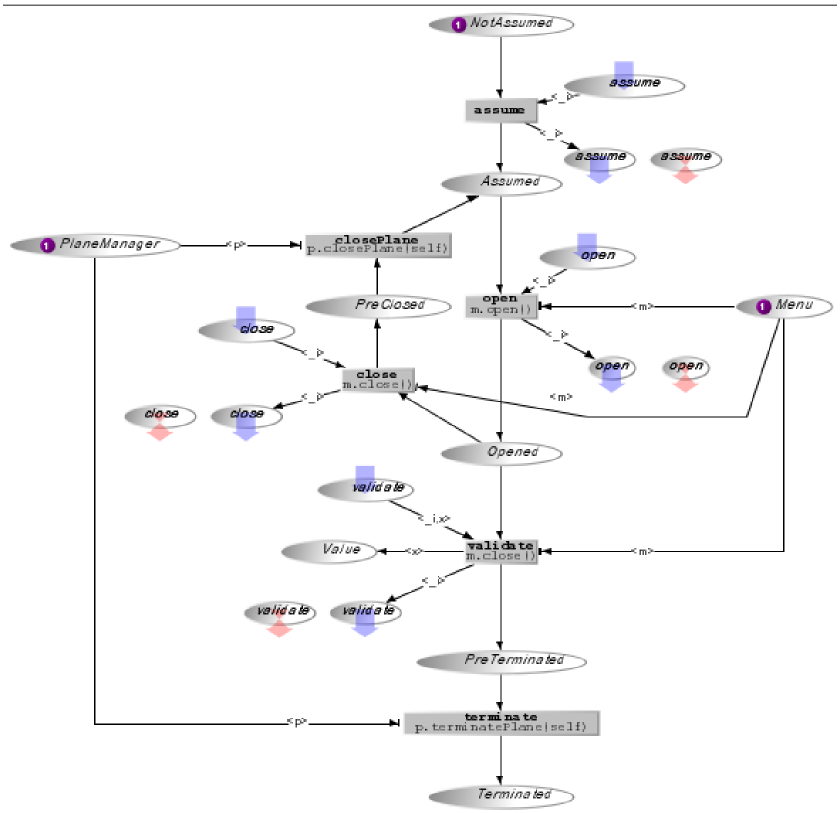

Figure 11. ObCS of the class MerfistoPlane

The class MefistoPlane is also an ICO class. Graphical information is added with respect to the class MefistoPlaneManager in order to describe how the plane is rendered on the screen. This informat ion is given on Figure 12 while Figure 10 gives the IDL description, Figure 11 descr ibes the behaviour of MefistoPlane and Figure 13 presents the rendering function. It is interesting to notice that this class does not feature an activation function. This is due to the fact that all the user interaction on a plane takes place through the MefistoPlaneManager class.

```
public class WidgetPlane {
   //Attributes
          //A button to open the menu for the change of frequency
          Button freqButton ;
          //A label to display the name of the plane
          Label label;
   //Rendering methods
          void show () {//show plane
          }
          void showAssumed () {//show plane as assumed
          }
          void showOpened () {//show plane as opened
          }
          void showTerminated () {//show plane as terminated
          }
          void setFreq(short x) {//show the new frequency
          }
}
```

Figure 12. The presentation part of the class MefistoPlane

ObCS Element	**Feature**	**Rendering method**
Place Assumed	token entered	showAssumed
Place Opened	token entered	showOpened
Place Terminated	token entered	showTerminated
Place Value	token <x> entered	setFreq(x)

Figure 13. The rendering function of the class MefistoPlane

5.3.3.3 The class MefistoMenu

This class is in charge of the interaction taking place through the data-link menu that is opened by clicking on the button FREQ on the plane label.

```
interface MefistoMenu {
   void open();
   void close();
   void send();
   void setValue(in short x);
};
```

Figure 14. IDL description of the class MefistoMenu

Figure 14 provides the set of services offered to the other objects of the application; Figure 15 describes its behaviour.

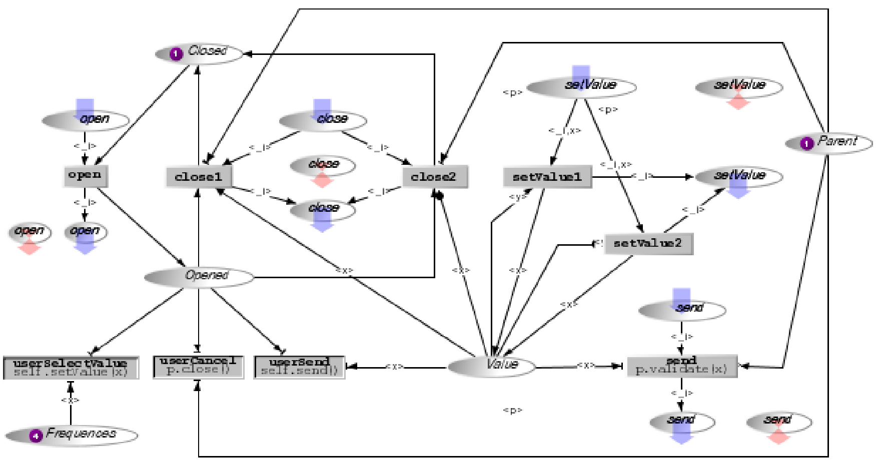

Figure 15. ObCS of the class MefistoMenu

```
public class WidgetMenu {
   //Attributes
          //Button to validate or cancel the current choice for frequency
          Button sendButton, cancelButton ;
          //A comboBox to show the set of possible frequency
          ComboBox freqComboBox;
   //Rendering methods
          void show () {//show menu as opened
          }
          void hide () {//hide menu
          }
}
```

Figure 16. The presentation part of the class MefistoMenu

Widget	Event	Service
sendButton	actionPerformed	userSend
abortButton	actionPerformed	userCancel
freqComboBox	select	userSelectValue

Figure 17. The activation function of the class MefistoMenu

Figure 16, Figure 17 and Figure 18 give the presentation part of the class MefistoPlane.

ObCS Element	Feature	Rendering method
Place Opened	token enterred	show()
Place Closed	token enterred	hide()

Figure 18. Rendering function of the class MefistoMenu

This description still lacks the code of the functions given in Figure 16 and in Figure 12 for describing precisely the graphical behaviour of the classes. This is not given here for space reasons.

6 THE INTEGRATION OF THE MODELS: CTT-ICO INTEGRATION

6.1 Integration Framework

The integration framework we have followed takes full advantage of the specific tools that we have developed initially in a separate manner. One advantage of this separation is that it allows for independent modification of the tools, provided that the interchange format remains the same.

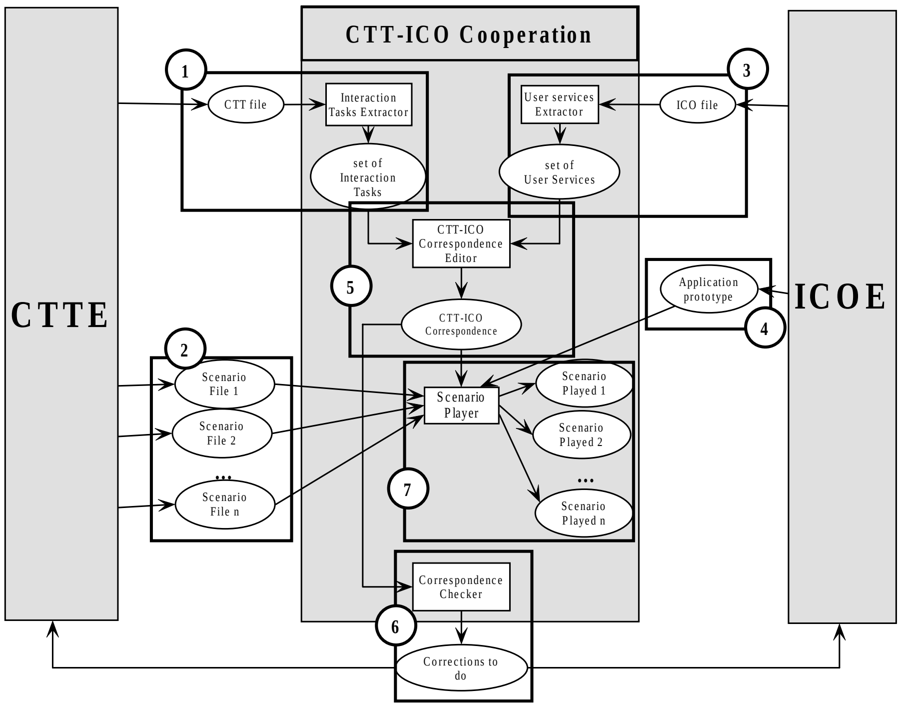

Figure 19. The framework for CTTE – PetShop integration

We have previously investigated the relationship between task and system models. For instance in (Palanque et al. 95) we proposed a transformation mechanism for translating UAN tasks descriptions into Petri nets and then checking whether this Petri net description was compatible with system modelling also done using Petri nets. In (Palanque et al. 97) we presented the use of CTT for abstract task modelling and high level Petri nets for low-level task modelling. In that paper the low-level task model was used in order to evaluate the "complexity" of the tasks to be performed, by means of performance evaluation techniques available in Petri net theory.

The two notations model slightly different aspects: CTT is a notation for task modelling whereas ICO is a notation for specifying concurrent systems, thus an automatic conversion from one notation to the other one would have been difficult. We have preferred a different solution that is easier to implement and better refers to the practise of user interface designers. Indeed, often designers use scenarios for many purposes and to move among the various phases of the design cycle. So, they can be considered a key element in comparing design solution from different viewpoints.

6.1.1 CTT Environment

The different parts of the framework for CTT-PetShop integration are shown in Figure 19 and referred by means of numbers. For instance, the outputs provided by CTT environment and their processing are highlighted on Figure 19 as part 1 and part 2. As described above, CTT environment provides a set of tools for engineering task models. For the purpose of integration we only use the interactive tool for editing the tasks and the simulation tool for task models that allows scenario construction from the task models. Thus the two main outputs are a set of task models and a set of scenarios. These two sets are exploited in the following way:

- from the ConcurTaskTrees specification a set of interaction tasks is extracted. This set represents a set of manipulations that can be performed by the user on the system (part 1 of Figure 19),
- the set of scenario is used as is by the integration tool (part 2 of Figure 19).

6.1.2 ICO Environment

The outputs of the ICO environment and their processing are highlighted by part 3 and part 4 of Figure 19). Amongst the features of the ICO environment (PetShop) presented in section 5.3.2, the one that is used for the integration is the tool for editing the system model. It allows executing the system model.

From this specification we extract a set of user services (part 3 of Figure 19) and from the ICO environment we use the prototype of the system modelled (part 4 of Figure 19).

A user service is a set of particular transitions that represents the functionalities offered to the user by the system. These transitions are performed when and only when they are fireable and the corresponding user actions are performed (which is represented by the activation function in the ICO formalism).

6.1.3 The Correspondence Editor

The activities that are managed by the correspondence editor correspond to part 5 and part 6 of Figure 19.

The first component of the correspondence editor relates interaction tasks in the task model to user services in the system model (part 5 of Figure 19). When the task model is refined enough, the leaves of the task tree represent low-level

interactions on the artefacts. It is then possible to relate those low-level interactive tasks to user actions in the system model that are represented, in the ICO formalism, by user services.

In order to check that this correspondence is valid we have developed a basic model checker (part 6 of Figure 19). Currently this tool checks structural constraints on the correspondence, namely the number of interactive tasks is the same as the number of user service. Further properties that should be checked by the model checker correspond to the verification and validation phase in the development process. Validation phase relates to the question "do we have modelled the right system?" while the verification phase address the question "do we have modelled the system right?". In the context of ICO-CTT integration for the verification phase the model checker addresses the following two “a)” questions; questions “b)” are still to be taken into account:

a. "are there at least as many user services in the ICO specification as interaction tasks in the CTT model ?",
b. "are all the possible scenarios from the task model available in the system modelled ?".

In the context of ICO-CTT integration for the validation phase the tool addresses the following two questions:

a. "are there more user services in the ICO specification than interaction tasks in the CTT model ?", and,
b. "are there scenarios available in the system model that are not available in the task model?".

If the answer is yes for one of these two sub rules, the system modelled offers more functionalities than expected by the task model described with CTT. This leads to two possible mistakes in the design process. Either the system implements more functions that needed or the set of task models built is incomplete. In the former case the useless functionalities must be removed. In the latter case either task models using this functionality are added or the use of this functionality will never appear in any of the scenarios to be built.

The role of the correspondence checker is to notify any inconsistency between the CTT and the ICO specifications. Future work will be dedicated to provide recommendations on how to correct these mistakes.

In this part a CTT-ICO correspondence file that stores the mapping between elements in the task and system models is produced.

6.1.4 Execution: the Scenario Player

As a scenario is a sequence of tasks and as we are able to put a task and a user service into correspondence, it is now possible to convert the scenarios into a sequence of firing of transitions in the ICO specification.

An ICO specification can be executed in the ICO environment and behaves according to the high-level Petri net describing its behaviour. As the CTT scenarios can be converted into a sequence of firing of transitions, it can directly be used to drive the execution of the ICO specification.

To this end we have developed a tool dedicated to the execution of an ICO formal description of a case study driven by a scenario extracted from a task model (see Part 7 of Figure 19).

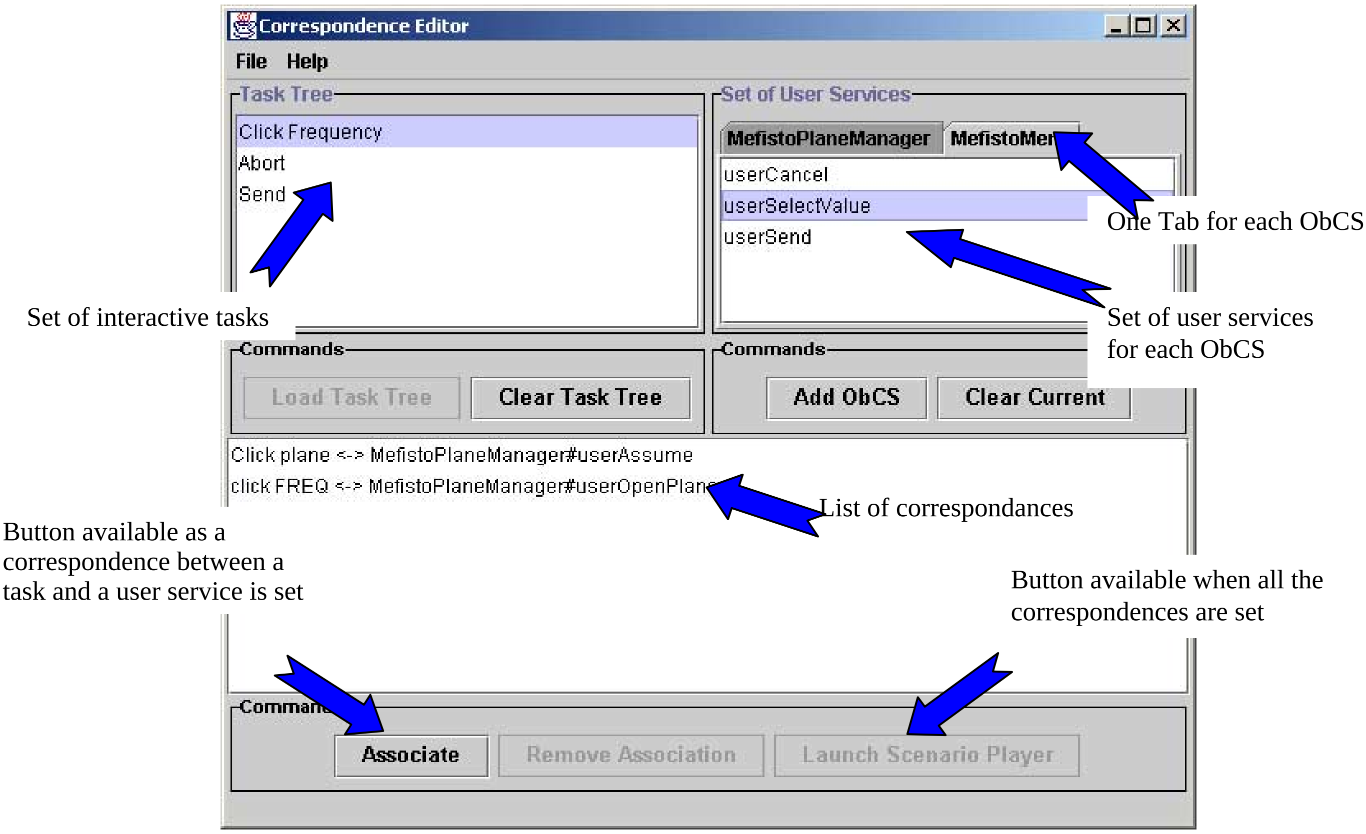

Figure 20. Association of interactive tasks and user services

6.2 Application on the case study

This section presents the application of the integration framework presented in section 6.1 to the Air Traffic Control case study presented in 5.1.

Figure 20 presents the correspondence editor introduced in section 6.1.3. The left-hand side of the window contains the task model that has been introduced in section 5.2 and loaded into the correspondence editor. In the case study under consideration only one task model can be loaded. However, if cooperative task models are considered the correspondence editor makes it possible to include several task models. In such a case, the "Task Tree" panel includes tabs widget for each task model. In this panel the set of interactive tasks are displayed. On the right-hand side of Figure 20 the panel "Set of User Services" displays the set of user services in the ICO specification that has been loaded. Here again it is possible to load several ICOs. The set of user services of each ICO appears in a separate tab widget.

The lower part of the window in Figure 20 lists the set of associations that have been created when all the user services loaded in the ICOs have been associated with all the interactive tasks loaded in the "Task Tree" panel. Then, the "Launch Scenario Player" button is available.

Clicking on this button opens the window presented in Figure 21 corresponding to the scenario player. This tool allows for loading a scenario (produced using CTTE tool presented in Figure 4) and executing it in Petshop. The scenario can thus be used to replace user interactions that would normally drive the execution of the ICO specification.

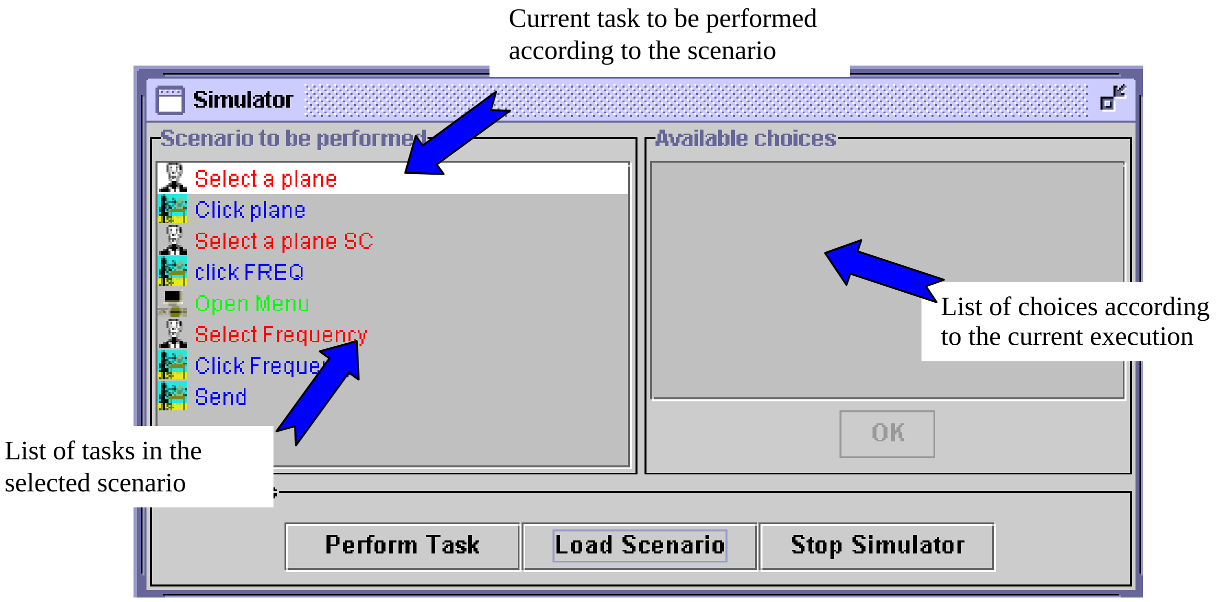

Figure 21. The scenario player

The right-hand side of Figure 21 presents the set of actions in the selected scenario. The first line in the scenario represents the current task in the scenario. In Figure 21 the current task is "Select a plane" and is a user tasks i.e. the task is performed entirely by the user without interacting with the system. Clicking on the "Perform Task" button triggers the task and next task in the scenario becomes the current task. Figure 22 shows the scenario player in use. The right-hand side of the figure shows the execution of the ICOs specification with the two main components: the Air Traffic Control application with the radar screen and the ATC simulator allowing for test purpose to add planes in the sector.

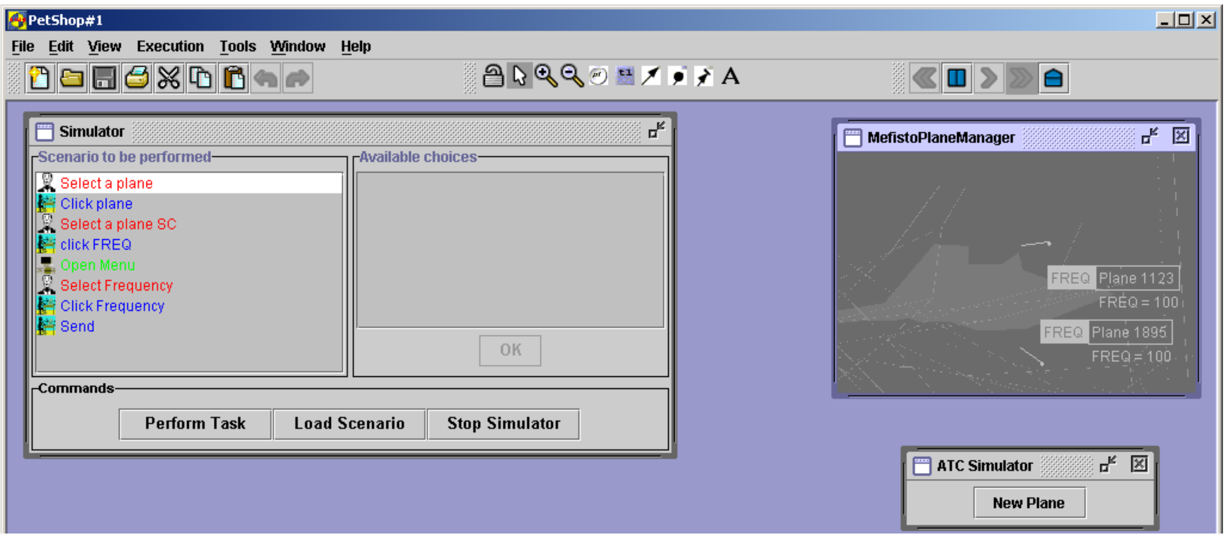

Figure 22. Execution of the scenario of the system

Some tasks of interactive or application category require runtime information to be performed. For instance this is the case of interactive task “Click plane” that corresponds to the user’s action of clicking on a plane. Of course the click can only occur on one of the “current” planes in the sector and thus, the identification number cannot be known at design time and thus cannot be represented in the task model.

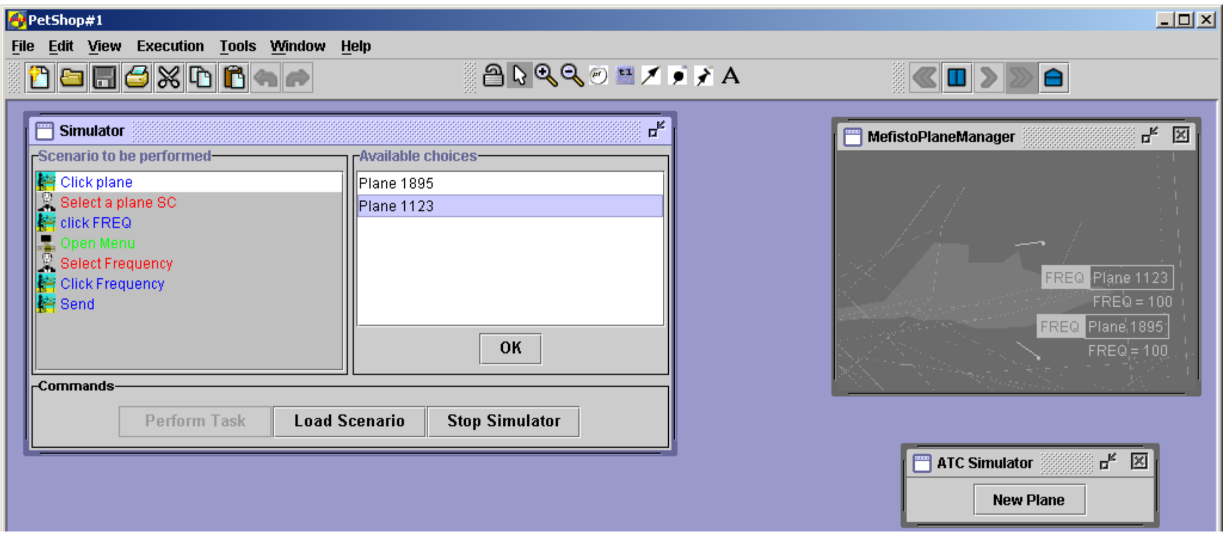

Figure 23. Interaction between scenario and current execution: planes IDs are selected at runtime

Figure 23 provides an example of this aspect. Triggering the action “Click plane” in the task model requires a parameter i.e. a plane identifier. As this interactive task has been related to the user service “userAssume” (in the correspondence editor) the triggering of this task starts off the corresponding user service. However, the triggering of this service requires one of the values in the input place of the transition userAssume in the ObCS of the class MefistoPlaneManager (see Figure 7) i.e. one of the objects planes in the place Planes. In order to provide those values to the scenario player the set of all the objects in the place Planes is displayed on the right-hand side of the scenario player (see Figure 23).

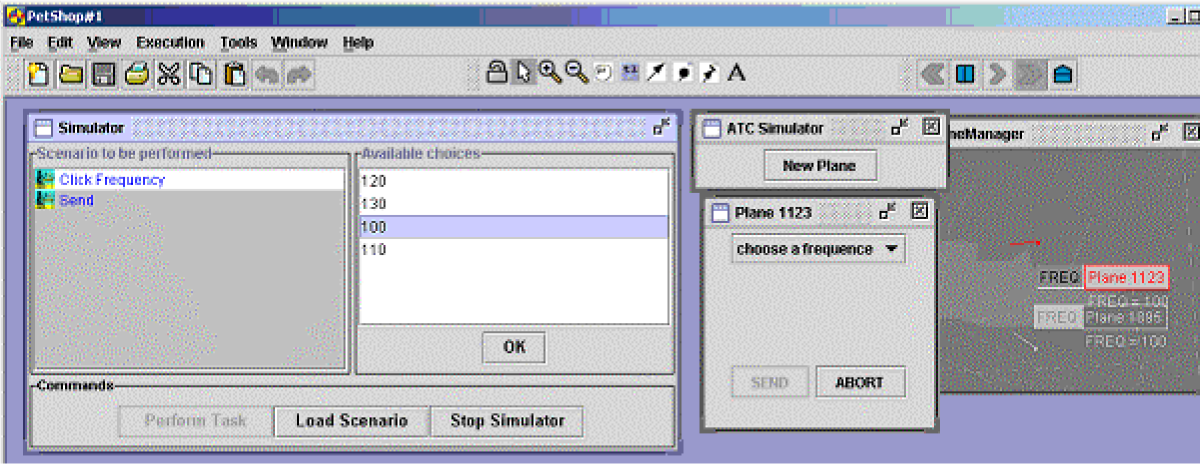

Figure 24. Interaction between scenario and current execution: values for frequency are selected at runtime

Figure 24 shows the same interaction occurring while selecting a value for the frequency. The set of frequencies in the place Frequencies (see Figure 15) is displayed for user's selection in the scenario player.

The tool shows a dialogue window when the scenario has been successfully played on the description of the application using the ICO formalism. A scenario fails when at some point no action can be performed and the list of actions still to be performed is not empty.

7 CONCLUSIONS

This paper has presented work that has been done in order to bridge the gap between task modelling and system modelling. The bridge is created by means of scenarios, which are considered here as sequences of tasks mapped onto sequences of actions in the system model. The use of scenarios is common practise in the design of interactive applications. We can thus obtain a design cycle that is thoroughly supported by dedicated software tools.

The environment proposed for both task modelling and scenarios generation supports the editing of cooperative tasks, while that for editing and executing the formal description of system models supports distributed execution of models according to the CORBA standard. On the system modelling side, further work is currently under way in order to ease the editing of the presentation part of the ICO models. Indeed, currently both activation and rendering functions are edited in a textual way, while graphical editing through direct manipulation would make this task easier. The use of PetShop requires skill in Petri net modelling as well as in advanced Java programming. Currently the tool is far from being ready to use by non-programmers. However, we are working on making it more usable by adding documentation and online help. We have already worked on the usability aspects and added functions such as "cut and paste" and "undo". We have also prepared tutorial and demo of the tools. Tutorials are available on the web page of the tool (http://lihs.univ-tlse1.fr/petshop) while demo as still under development.

Future work will be dedicated to defining formal mappings between the two notations.

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14. Abstract

Representatives of NATO member nations, Partnership for Peace countries and non-NATO member nations met in Paris (Val de Grâce Hospital) from 11 to 13 June 2001, for a Specialists Meeting on "Human Factors problems in the 21st century". This meeting was particularly concerned with Human Factors problems which have appeared since what is known as the Revolution in Military Affairs (RMA) dating from the end of the Cold War.

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